W. B. No. 738]

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The Weather Bureau desires that the MONTHLY WEATHER REVIEW shall be a medium of publication for contributions within its field, but the publication of contributions is not to be construed as official approval of the views expressed.

BACK NUMBERS OF THE REVIEW WANTED.

The Weather Bureau has not enough of the following numbers of the MONTHLY WEATHER REVIEW to meet even urgent requests for filling up files at institutions where the REVIEW is constantly being referred to. The return of any of these or of any 1919 or 1920 issues, especially November, 1919, will be greatly appreciated. The attached addressed franked slip may be used for this purpose, or one may be had on application to the Chief, U. S. Weather Bureau, Washington, D. C.

1914: January, February, March, April, September, October, December.
1915: May, June, July, August.
1916: January, August.
1917: June.
1918: February, September.
1919: Any issue, especially November.
1920: Any issue, especially January.
SUPPLEMENT No. 3.

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CHARLES F. BROOKS, Editor.

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LOCAL FORECAST STUDIES—SUMMER RAINFALL.

By Thomas Arthur Blair, Meteorologist.

[Weather Bureau Office, Dubuque, Iowa, May 14, 1921.]

[Presented in part before the American Meteorological Society at Chicago, Dec. 28, 1920.]

SYNOPSIS.

Observations at Dubuque, Iowa, at 7 a. m., 90th meridian time, for June and July, for the 20-year period, 1901 to 1920, inclusive, are tabulated with reference to the occurrence of precipitation within the following 12 and 24 hours, and classified according to the following elements:

a. Height of barometer, reduced to sea level.
b. Change in height of barometer during past 12 hours.
c. Change in temperature during past 24 hours.
d. Amount of cloudiness.
e. Relative humidity.

A further classification according to (*a*) wind direction, and (*b*) kind of clouds is based on a 30-year period for the four months, May to August, inclusive.

The results are shown in a series of tables and curves, based on the relation which the number of observations followed by rain within 12 or 24 hours bears to the total number of observations within the group. These tables and curves are intended to show the more important relationships existing between the data of the morning observation and the rain frequency during the following 12 and 24 hours, and it is suggested that a series of simple classifications, such as these, could be made at numerous stations throughout the United States, and would furnish material of much value.

Attention has frequently been called to the possibility of making use of local observational data as an aid to forecasting, and Bruno Rolf in Sweden has attained some success in developing a formula to express the probability of rain as deduced from local conditions.[1]

Without having seen more than a brief summary of his paper, the present study was begun as a preliminary attempt to devise a practical and simple method of making a statistical statement of the probability of rain from local conditions obtaining at the time of the regular morning observations of the Weather Bureau.

Observations at 7 a. m., 90th meridian time, at Dubuque, Iowa, for June and July for the 20-year period, 1901 to 1920, inclusive, were tabulated with reference to the occurrence of precipitation within the following 12 and 24 hours. The observations were then classified according to the following elements:

a. Height of barometer, reduced to sea level.
b. Change in height of barometer during past 12 hours.
c. Change in temperature during past 24 hours.
d. Amount of cloudiness.
c. Relative humidity.

[1] R. H. Weightman, Mo. Weather Rev., Mar., 1920, 48: 154-156.

The results are depicted in a series of curves, showing the relation, expressed as a percentage, which the number of observations followed by rain in 12 or 24 hours bears to the total number of observations within the group. A total of 1,217 observations is listed, but the number falling under extreme conditions is small, so that only the three or four central points of the curves are based upon a sufficient number of observations to eliminate in a fair degree the effects of chance. But these are the most important, of course, not only because of their much more frequent occurrence but also because the forecasts are more doubtful under these ordinary conditions than under extreme conditions.

The total probability of rain in 12 hours under all conditions is 0.31. The "All observations" curve in figure 1 shows that when the barometer is under 29.75 inches this rises to 0.62, and when the barometer is over 30.25 it falls to 0.06. When the barometer is falling the probability is increased by about 10 points, except when the barometer is high, and then it seems less likely to rain with falling than with rising pressure. When the morning observation shows a cloudy sky as well as a falling barometer the chances of rain in 12 hours are increased by from 20 to 40 points, and range from 83 per cent with a low barometer to 33 per cent with a high barometer.

I use the terms falling and rising barometer as indicating the change in 12 hours, and falling and rising temperature for the 24-hour change. The average barometric reading at the morning observation was found to be 0.055 inch higher than at the evening observation. This was taken as the value of the diurnal change, and a rise of 0.05 inch or less was classed as a falling barometer.

With increasing subdivision the results become more doubtful, but the greatest probability of rain is indicated when the sky is cloudy, the barometer falling, and the temperature also falling. Fifteen observations under these conditions with the barometer between 29.75 and 29.85 gave rain in 93 per cent of the cases, while 24 observations under the same conditions except that the temperature was rising gave a percentage of 62. The same general relation holds for all groups with the barometer below 30.05, but when the pressure rises above that point the position of the lines is reversed, and it seems more likely to rain with rising temperature. I can not say whether or not these results are consistent with the experience of forecasters.

CORRIGENDA.

In the Annual Index to the Monthly Weather Review for 1920, the following corrigenda were inadvertantly omitted:
February Review, back cover, data for January, 1920.
May Review, back cover, data for March and April, 1920.
August Review, back cover, data for May and July, 1920.
November Review, back cover, data for October, 1920.

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The least probability of rain is also connected with falling temperature, but accompanied by clear weather and a rising barometer, as shown by the lowest curve in figure 1. Under these conditions for all barometric readings above 30 inches it has rained in less than 5 per cent of the cases, and for readings above 30.20 inches it has never rained.

Figure 2, giving the same analysis for rain in 24 hours, shows practically identical relations, with all percentages somewhat higher, of course, but not higher with reference to the total probability of rain, which is here 0.46 instead of 0.31.

In figures 3 and 4 the classification is based upon the amount of change in pressure during the preceding 12 hours. The probability for all observations decreases rapidly from a practical certainty of rain when the fall has been a quarter of an inch, to 12 or 13 per cent in 12 hours and 26 per cent in 24 hours when there has been a rise of a quarter of an inch. The probability is increased considerably for all groups, except where it is already a certainty, if the weather is also cloudy at observation, and decreased if it is clear. As in the previous computation, the probability is also increased with falling temperature when the weather is cloudy and decreased slightly with falling temperature when the sky is clear.

In figures 5 and 6 the abscissæ are again changes in barometric height, and the same "All observations" curve is shown as in figures 3 and 4. The other curves that are closely grouped about the average show the probability of rain with falling and with rising temperature, and with temperature above and below normal. We conclude from the fact that they follow the "All observations" curve so closely that, whether the temperature is falling or rising, whether it is above or below normal, gives very little indication of the probability of rain.

The shorter upper and lower curves in these figures show a considerable increase in rain probability with high humidity and a rather less-marked decrease with low humidity. The average humidity at the morning observation at Dubuque is 78 per cent. It will be recognized that the use of the morning humidity data for any purposes of forecasting is complicated by the fact that at times we do not in reality obtain free-air humidities, but record purely local conditions arising from surface radiation and light wind movement. Hence morning humidities do not bear a very close relation to subsequent rainfall. Tables 1 and 2 give in detail the data upon which all these curves are based.

In the foregoing discussion two important observational facts affecting the probability of rain have not been considered. These are wind direction and kind of clouds. Because of the increased subdivision made necessary by the consideration of these factors, it seemed best to tabulate a larger number of observations, and, accordingly, the morning observations were listed for May, June, July, and August from July, 1889, to August, 1920, inclusive, except 1895 and a portion of 1894, during which observations were missing. A total of about 3,500 observations was tabulated with the results shown in Tables 3 and 4. Table 3 gives separately for four barometric levels, and for falling and rising barometer, the total number of observations with clear, partly cloudy and cloudy sky for each of eight wind directions, also the number followed by rain in 12 and in 24 hours, the "expected number," and the percentage which the number with rain bears to the total number. Table 4 is the same except that cloud classification is substituted for wind direction.

The "expected number"[2] is the number to be expected on the assumption that the rainfall is independent of wind direction, or of kind of clouds. It is obtained by apportioning the total number of observations with rain to the different wind directions or cloud forms in the ratio which the number of observations in that group bears to the total number of observations. An example will make this clear. In Table 3 with barometer 29.94 or under and falling, the total number of observations is 707, the number with rain in 12 hours is 395, and the total from the north is 34. The "expected number" is then obtained from the equation

$$34 : 707 = x : 395, \text{ from which } x = 19.0$$

A comparison of the "expected number" with the actual number of rainy days, 14 in this case, shows at a glance whether the wind direction or cloud form is wetter or drier than the average. An "expected number" greater than the recorded number means that rains are less frequent than the average, as with the north wind, in this example, which is a dry wind.

We may note in Table 3 that with the barometer under 29.94 and falling, it will rain within 12 hours in 56 per cent of the cases, and within 24 hours in 69 per cent; but under the same barometric conditions and with an east wind and a cloudy sky at the morning observation, it will rain within 12 hours 88 per cent of the time, and within 24 hours 95 per cent. This is the case in which there is the greatest probability of rain, but under similar conditions with a northeast wind the probability is nearly as great. On the other hand, with the barometer over 30.15 and rising, out of 143 observations in which the wind was north, northeast, or east and the sky clear, it has never rained within 12 hours, and only 17 times, 12 per cent, within 24 hours. In these two cases definite forecasts could be made without the aid of a weather map. Other cases are intermediate, of course, but used in connection with the weather map will give some indication of the porbability of showers.

The percentages of totals given at the bottom of Table 3 are shown graphically in figure 7, and we see that with a falling barometer the winds which are the best indicators of rain are northeast, east, southeast, and south, east showing the greatest percentage. When the barometer is rising, south and southwest winds show the greatest probability of rain; even with a west wind rain is as probable as with east and southeast.

Figure 8 gives a similar summary representation of Table 4. The first fact noted will be that the stratified clouds, except cirro-stratus, are the best indicators of rain, the percentage varying inversely with the height, i. e., decreasing in the order, stratus, strato-cumulus, alto-stratus. When the barometer is rising alto-cumulus displaces alto-stratus for third position, but with falling barometer it drops distinctly lower. When the barometer is falling, cirro-cumulus clouds rank very low for the 12-hour period, but high for the 24-hour period. Hence, when cirro-cumuli are observed with a falling barometer at the morning observation, one can say that it very probably will not rain during the day, but very probably will rain during the following night. In the case of cirro-stratus with rising pressure the curves for 12-hour and 24-hour rain frequency show a similar, though less pronounced, divergence of trend. The absence of morn-

[2] Chapman, E. H., *Quart. Jour. Roy. Met. Soc.*, 1914, **40**: 349.

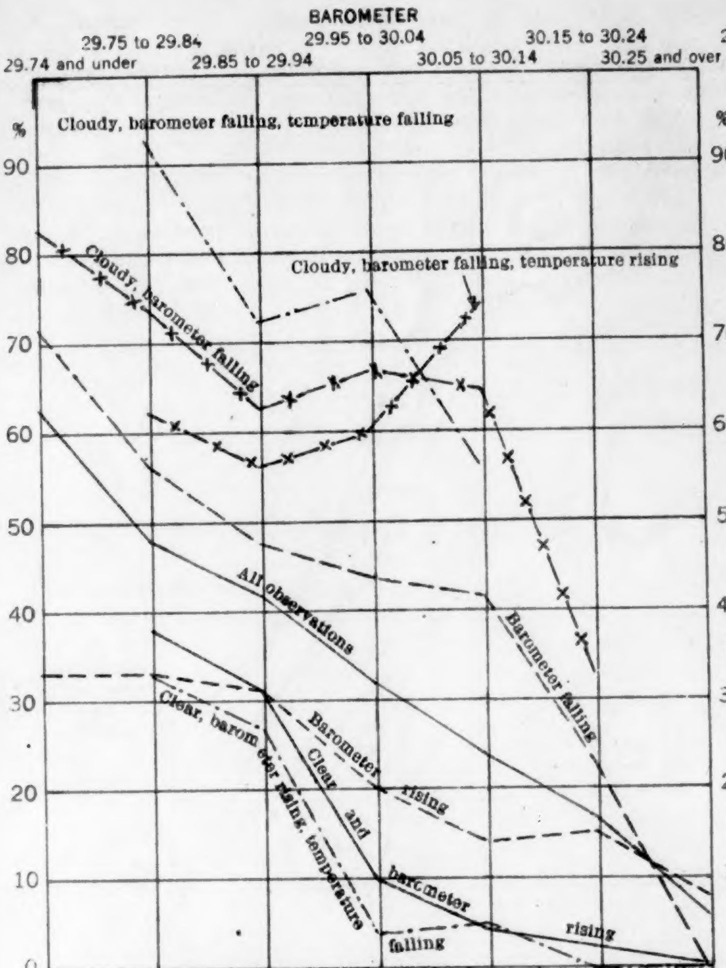


FIG. 1.—Percentage of rain within 12 hours after 7 a. m. observation as related to height of barometer and other factors.

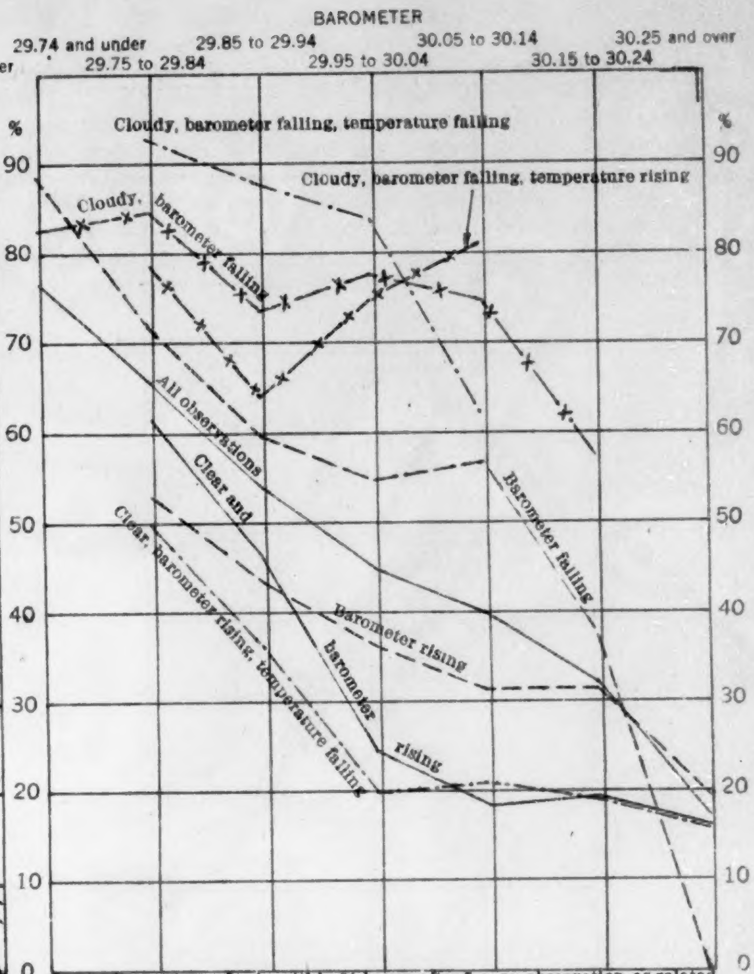


FIG. 2.—Percentage of rain within 24 hours after 7 a. m. observation as related to height of barometer and other factors.

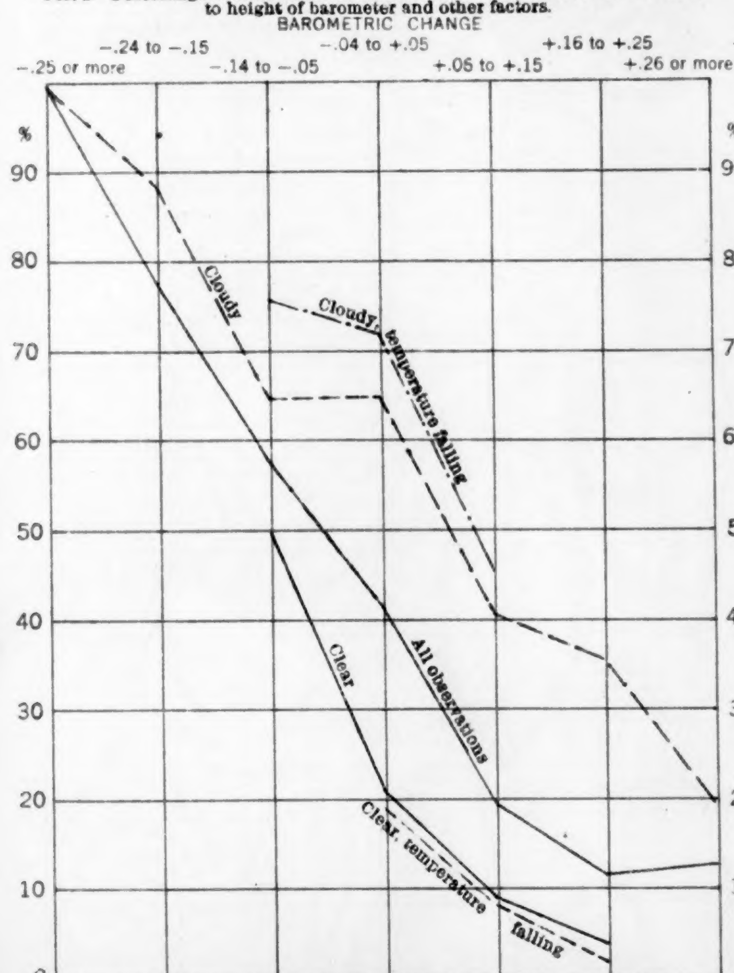


FIG. 3.—Percentage of rain within 12 hours after 7 a. m. observation as related to change in barometer and to state of weather.

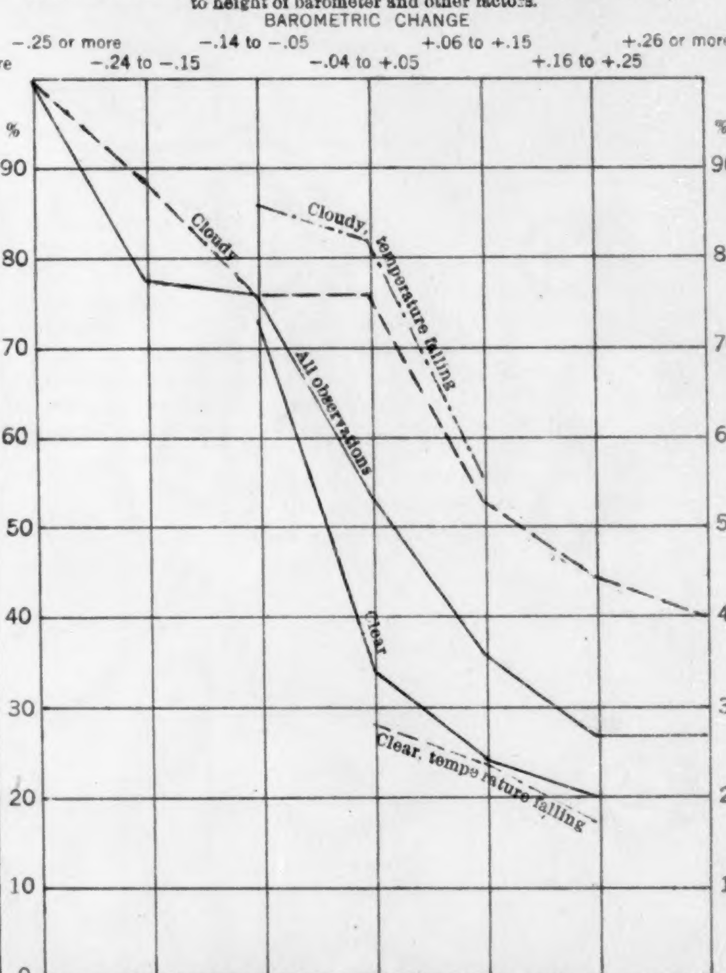


FIG. 4.—Percentage of rain within 24 hours after 7 a. m. observation as related to change in barometer and to state of weather.

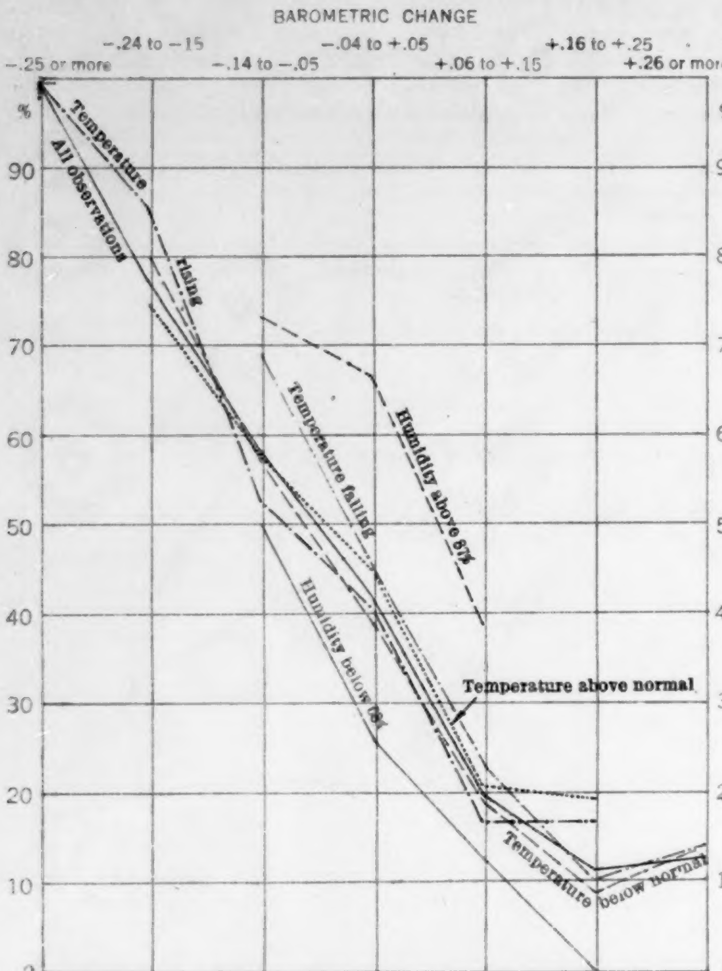


FIG. 5.—Percentage of rain within 12 hours after 7 a. m. observation as related to change in barometer and to temperature and relative humidity.

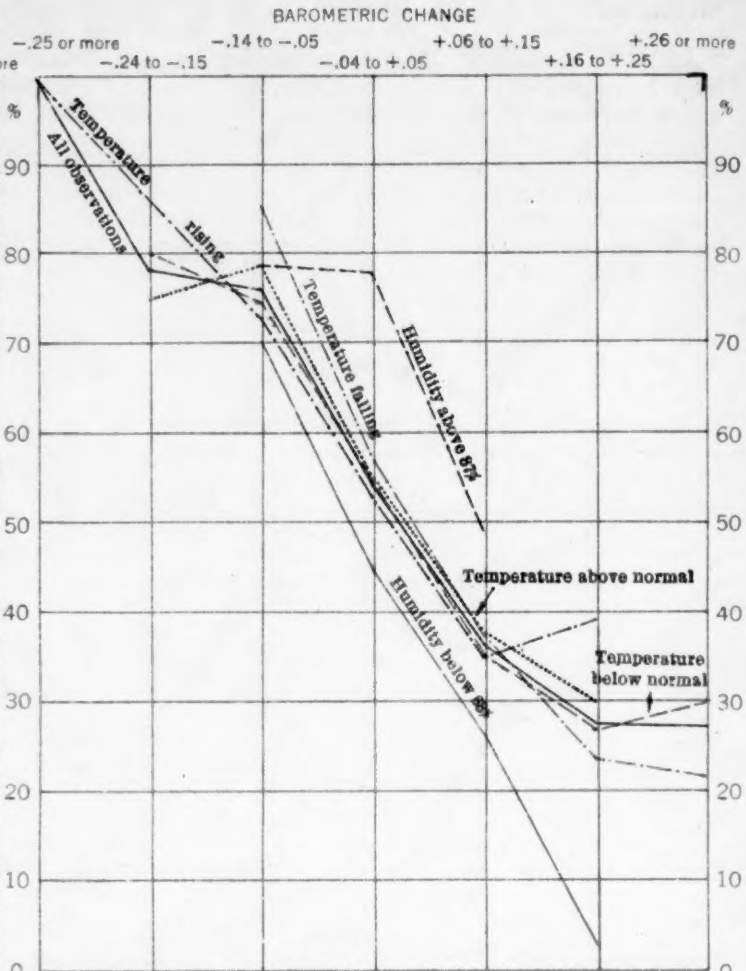
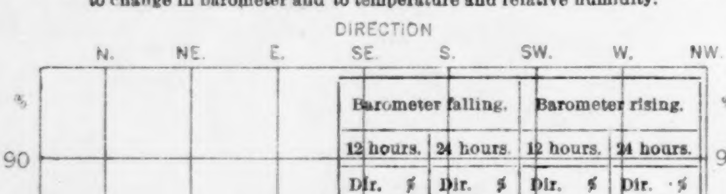
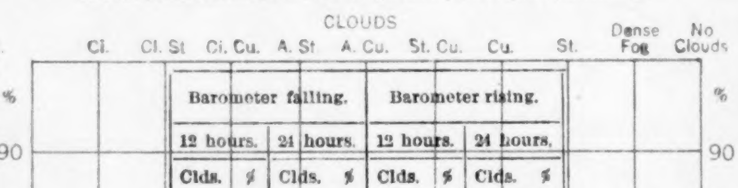


FIG. 6.—Percentage of rain within 24 hours after 7 a. m. observation as related to change in barometer and to temperature and relative humidity.



Barometer falling.				Barometer rising.			
12 hours.		24 hours.		12 hours.		24 hours.	
Dir.	%	Dir.	%	Dir.	%	Dir.	%
E.	64	E.	72	S.	29	SW.	49
NE.	53	SE.	64	SW.	28	S.	47
S.	61	S.	64	SE.	21	SE.	38
SE.	47	NE.	63	W.	21	W.	37
W.	43	SW.	56	E.	19	E.	37
NW.	38	W.	55	NE.	18	NE.	29
SW.	36	N.	45	N.	17	NW.	28
N.	36	NW.	44	NW.	17	N.	26

FIG. 7.—Percentage of rain within 12 and 24 hours as related to wind direction. Based on 3,390 observations at Dubuque Iowa.



Barometer falling.				Barometer rising.			
12 hours.		24 hours.		12 hours.		24 hours.	
Clds.	%	Clds.	%	Clds.	%	Clds.	%
St.	55	St.	69	St.	36	St.	51
St. Cu.	53	St. Cu.	65	St. Cu.	35	Sky	46
A. St.	46	A. St.	63	A. St.	28	A. Cu.	44
A. Cu.	41	Ci. Cu.	62	A. Cu.	28	Cu.	41
Ci. St.	34	A. Cu.	58	Fog	23	A. St.	39
Ci.	34	Ci. St.	55	Ci. Cu.	17	Ci. St.	37
Cu.	32	Ci.	53	Ci. St.	16	Ci.	31
Fog	29	Cu.	47	Ci.	13	Ci. Cu.	26
Ci. Cu.	28	Fog	41	Cu.	13	Fog	25
0	15	0	31	0	6	0	18

FIG. 8.—Percentage of rain within 12 and 24 hours as related to kind of clouds. Based on 3,400 observations at Dubuque, Iowa.

ing clouds is the best indication that there will be no rain, but it is by no means a certain indication, and with a low barometer there will be showers within 12 hours on one-fifth of the days. The presence of cumulus clouds, occurring most frequently in amounts of from one to three tenths, does not add greatly to the probability of rain. The number of dense fogs recorded is small, but only when the barometer is low do they seem to offer any indication of rain. These are a few of the facts indicated by the tables and figures. A detailed study will reveal many others.

Finally, figure 9 represents in a manner similar to figure 1, the percentage of rain frequency associated with certain wind directions when the sky is overcast by stratus or strato-cumulus clouds. We note here in curves B and B′ and E and E′ that when the barometer is between 29.95 and 30.14 and the wind southeast or south, there is a greater tendency to rain with a rising than with a falling barometer. Curves B′ and E′, however, are based on a small number of cases, and hence are subject to some doubt. A complete presentation of the details of Tables 3 and 4 would require 480 curves of this kind, but many points in these curves would be based on too few observations to be significant.

In this study I have attempted to show the more important relationships existing during the summer months in northeastern Iowa between the data of the morning observation and the frequency of rain during the following 12 and 24 hours. In these months the precipitation is mostly in the form of thundershowers, and the correlation of rainfall with other elements is probably less marked than in the winter months. No attempt has been made to combine all the observed conditions into a single mathematical expression for calculating directly the actual probability at any given time. It is a complex matter, and any formula of value would need to rest upon more than a single series of observations at one station. It is thought, however, that a series of simple, nonmathematical classifications, such as I have attempted, could be easily made at numerous stations throughout the United States, and would furnish material of much value, from which, possibly, precepts of general, or at least wide, application could be deduced. It is not assumed that such results would displace synoptic charts in forecasting, but that they would furnish valuable aid to the forecaster, and especially to the local official in making definite forecasts for short periods in advance.

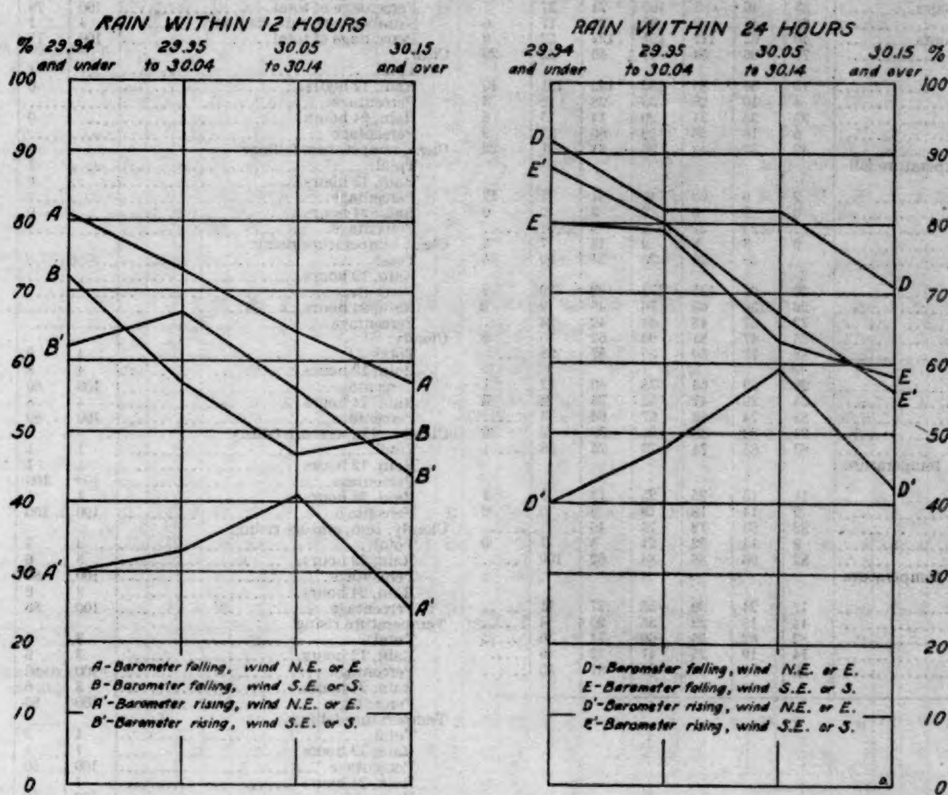


FIG. 9.—Relation between pressure, barometric tendency, wind direction, and subsequent rainfall at Dubuque, Iowa.

TABLE 1.—*Summer rainfall at Dubuque, Iowa, as related to height of barometer and other factors, based on observations at 7 a. m., 90th meridian time, for June and July for the years 1901 to 1920, inclusive—Total number of observations, 1,217.*

Height of barometer reduced to sea level.	29.74 and under.	29.75 to 29.84	29.85 to 29.94	29.95 to 30.04	30.05 to 30.14	30.15 to 30.24	30.25 or over.
All observations:							
Total number of observations	52	95	218	339	304	160	49
Number with rain, 12 hours	33	46	91	109	74	27	3
Percentage of total	63	48	42	32	24	17	6
Number with rain, 24 hours	40	63	117	154	122	52	9
Percentage of total	77	66	54	45	40	32	20
Barometer rising:							
Total	12	30	83	166	195	121	40
Rain, 12 hours	4	10	26	33	28	18	3
Percentage	33	33	31	20	14	15	8
Rain, 24 hours	5	16	36	59	60	37	9
Percentage	42	53	43	36	31	31	22
Clear, barometer rising, temperature falling:							
Total	2	6	22	46	61	37	19
Rain, 12 hours	0	2	6	2	3	0	0
Percentage	......	33	27	4	5	......	......
Rain, 24 hours	0	3	8	9	13	7	3
Percentage	......	50	36	20	21	19	16
Barometer falling:							
Total	40	65	135	173	109	39	9
Rain, 12 hours	29	36	65	76	46	9	0
Percentage	72	57	48	44	42	23	......
Rain, 24 hours	35	47	81	95	62	15	0
Percentage	88	72	60	55	57	38	......
Cloudy, barometer falling:							
Total	29	39	65	78	40	12	1
Rain, 12 hours	24	29	41	52	26	4	0
Percentage	83	74	63	67	65	33	......
Rain, 24 hours	24	33	48	61	30	7	0
Percentage	83	85	74	78	75	58	......
Cloudy barometer falling, temperature falling:							
Total	11	15	25	25	13	1	1
Rain, 12 hours	9	14	18	19	6	0	0
Percentage	82	93	72	76	46	......	......
Rain, 24 hours	9	14	22	21	8	1	0
Percentage	82	93	88	84	62	100	......
Cloudy, barometer falling, temperature rising:							
Total	17	24	39	55	27	11	......
Rain, 12 hours	14	15	22	33	20	4	......
Percentage	82	62	56	60	74	36	......
Rain, 24 hours	14	19	25	41	22	6	......
Percentage	82	79	64	75	81	55	......

TABLE 2.—*Summer rainfall at Dubuque, Iowa, as related to change in height of barometer and other factors, based on observations at 7 a. m., 90th meridian time, for June and July for the years 1901 to 1920, inclusive—Total number of observations, 1,217.*

Twelve-hour change in barometer.	−0.25 or more.	−0.24 to −0.15	−0.14 to −0.05	−0.04 to +0.05	+0.06 to +0.15	+0.16 to +0.25	+0.26 or more.
All observations:							
Total number of observations	4	9	97	460	547	85	15
Number with rain, 12 hours	4	7	56	194	110	10	2
Percentage of total	100	78	58	42	20	12	13
Number with rain, 24 hours	4	7	74	250	195	23	4
Percentage of total	100	78	76	54	36	27	27
Clear:							
Total	......	1	22	176	306	56	9
Rain, 12 hours	......	0	11	37	28	2	1
Percentage	......	......	50	21	9	4	11
Rain, 24 hours	......	0	16	59	73	11	2
Percentage	......	......	73	34	24	20	22
Clear, temperature falling:							
Total	......	1	4	43	137	47	8
Rain, 12 hours	......	0	1	8	11	1	0
Percentage	......	......	25	19	8	2	......
Rain, 24 hours	......	0	3	12	33	8	1
Percentage	......	......	75	28	24	17	12
Clear, temperature rising:							
Total	......	......	20	134	166	10	1
Rain, 12 hours	......	......	10	29	15	1	1
Percentage	......	......	50	22	9	10	100
Rain, 24 hours	......	......	13	47	39	3	1
Percentage	......	......	65	35	23	30	100
Cloudy:							
Total	4	9	63	188	143	22	5
Rain, 12 hours	4	8	41	123	58	8	1
Percentage	100	89	65	65	41	36	20
Rain, 24 hours	4	8	48	143	76	10	2
Percentage	100	89	76	76	53	45	40
Cloudy, temperature falling:							
Total	1	1	21	71	78	17	4
Rain, 12 hours	1	1	16	51	36	6	1
Percentage	100	100	76	72	46	35	25
Rain, 24 hours	1	1	18	58	42	7	1
Percentage	100	100	86	82	56	41	25
Cloudy, temperature rising:							
Total	3	7	43	119	67	5	1
Rain, 12 hours	3	6	27	73	24	2	0
Percentage	100	86	63	61	36	40	......
Rain, 24 hours	3	6	31	86	35	3	1
Percentage	100	86	72	72	52	60	100
Temperature rising:							
Total	3	7	71	321	282	18	1
Rain, 12 hours	3	6	38	131	49	3	0
Percentage	100	86	53	41	17	17	......
Rain, 24 hours	3	6	52	171	97	7	1
Percentage	100	86	73	53	34	39	100
Temperature falling:							
Total	1	2	26	139	265	67	14
Rain, 12 hours	1	1	18	63	61	7	2
Percentage	100	50	69	45	23	10	14
Rain, 24 hours	1	1	22	79	98	16	3
Percentage	100	50	85	57	37	24	21
Temperature above normal:							
Total	......	4	43	239	249	20	1
Rain, 12 hours	......	3	25	108	52	4	0
Percentage	......	75	58	45	21	20	......
Rain, 24 hours	......	3	34	131	94	6	0
Percentage	......	75	79	55	38	30	......
Temperature below normal:							
Total	4	5	54	221	298	65	14
Rain, 12 hours	4	4	31	86	58	6	2
Percentage	100	80	57	39	19	9	14
Rain, 24 hours	4	4	40	119	101	17	4
Percentage	100	80	74	54	34	26	29
Humidity above 87 per cent:							
Total	4	6	39	105	88	15	1
Rain, 12 hours	4	6	29	70	34	6	1
Percentage	100	100	74	67	39	40	100
Rain, 24 hours	4	6	31	82	43	9	1
Percentage	100	100	79	78	49	60	100
Humidity below 68 per cent:							
Total	......	2	10	77	80	24	6
Rain, 12 hours	......	1	5	20	10	0	1
Percentage	......	50	50	26	12	......	17
Rain, 24 hours	......	1	7	34	21	3	1
Percentage	......	50	70	44	26	12	17

Table 3.—*Summer rainfall at Dubuque, Iowa, as related to wind direction, state of weather, barometric height, and barometric tendency. Based on observations at 7 a. m., ninetieth meridian time, for May, June, July, and August, for the years 1889 to 1920, inclusive, except 1894 and 1895.*

BAROMETER FALLING.

	N.				NE.				E.				SE.				S.				SW.				W.				NW.				Total barometer falling.
	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	
BAROMETER 29.94 INCHES AND UNDER (REDUCED TO SEA LEVEL).																																	
Total	7	4	23	34	1	5	29	35	6	3	40	49	13	27	87	127	34	37	109	180	44	30	48	122	17	7	30	54	36	18	52	100	707
Rain in 12 hours:																																	
Number	2	0	12	14	0	2	24	26	1	1	35	37	5	11	69	85	14	17	80	111	11	13	20	44	3	3	21	27	7	7	37	51	395
Expected number				19.0				19.6				27.4				70.9				10.05				68.1				31.2				59.2	
Per cent			52	41			83	74			88	76		41	79	67	41	46	73	62	25	43	42	36			70	50	19	39	71	47	56
Rain in 24 hours:																																	
Number	2	2	15	19	0	2	26	28	1	1	38	40	6	17	75	98	18	25	80	132	22	22	26	70	7	4	23	34	14	9	41	64	485
Expected number				23.3				24.0				33.6				87.1				123.5				83.7				37.0				72.7	
Per cent			65	56			90	80			95	82		63	86	77	53	68	82	73	50	73	54	57			77	63	39	50	79	60	69
BAROMETER 29.95 TO 30.04 INCHES (REDUCED TO SEA LEVEL).																																	
Total	8	6	15	29	6	4	19	29	5	4	22	31	32	25	63	120	32	23	52	107	30	15	25	70	9	9	8	26	28	10	21	59	471
Rain in 12 hours:																																	
Number	1	2	9	12	1	2	12	15	1	1	18	20	5	5	43	53	11	11	31	53	7	3	18	28	3	2	3	8	2	0	6	8	197
Expected number				12.1				12.1				13.0				50.2				44.7				29.3				10.9				24.7	
Per cent				41				52			82	65	16	20	68	44	34	48	60	50	23	20	72	40				31	7		29	14	42
Rain in 24 hours:																																	
Number	1	3	9	13	2	2	13	17	3	1	19	23	13	11	54	78	17	15	38	70	15	6	19	40	5	4	3	12	2	3	7	12	265
Expected number				16.3				16.3				17.4				67.6				60.2				39.4				14.6				33.2	
Per cent				45				59			86	74	41	44	86	65	53	65	73	65	50	40	76	57				46	7		33	20	56
BAROMETER 30.5 TO 30.14 INCHES (REDUCED TO SEA LEVEL).																																	
Total	12	2	13	27	5	1	8	14	5	1	17	23	37	21	43	101	32	16	25	73	15	7	7	29	7	2	5	14	12	4	9	25	306
Rain in 12 hours:																																	
Number	1	0	9	10	1	0	5	6	1	0	10	11	7	6	22	35	4	6	15	25	3	1	4	8	2	1	3	6	3	0	5	8	109
Expected number				9.6				5.0				8.2				36.0				26.0				10.3				5.0				8.9	
Per cent				37				43				48	19	28	51	35	12		60	34				28				43				32	36
Rain in 24 hours:																																	
Number	1	0	10	11	2	0	6	8	1	0	11	12	13	14	27	54	9	12	20	41	8	3	5	16	2	2	3	7	4	0	7	11	160
Expected number				14.1				7.3				12.0				52.8				38.2				15.2				7.3				13.1	
Per cent				41				57				52	35	67	63	53	28		80	56				55				50				44	52
BAROMETER 30.15 INCHES AND OVER (REDUCED TO SEA LEVEL).																																	
Total	12	1	4	17	10	3	8	21	9	3	9	21	18	7	21	46	11	5	5	21	6	8	4	18	1	0	1	2	8	2	3	13	159
Rain in 12 hours:																																	
Number	1	0	2	3	0	0	5	5	2	2	7	11	1	4	9	14	2	2	3	7	2	3	2	7	0	0	0	0	0	0	2	2	49
Expected number				5.2				6.5				6.5				14.1				6.5				5.5				0.6				4.0	
Per cent				18				24				52			43	30				33				39				0				15	31
Rain in 24 hours:																																	
Number	2	1	2	5	0	2	7	9	4	3	7	14	4	6	12	22	4	2	4	10	2	4	2	8	0	0	0	0	0	0	3	3	71
Expected number				7.6				9.4				9.4				20.6				9.4				8.0				0.9				5.8	
Per cent				29				43				67			57	48				48				44				0				23	45
Total:																																	
Total				107				99				124				394				381				239				96				203	1,643
Rain in 12 hours:																																	
Number				39				52				79				187				196				87				41				69	750
Expected number				44.8				45.2				56.6				179.9				173.8				109.1				43.8				92.7	
Per cent				36				53				64				47				51				36				43				38	46
Rain in 24 hours:																																	
Number				48				62				89				252				253				134				53				90	981
Expected number				63.9				59.1				74.0				235.3				227.5				142.7				57.3				121.2	
Per cent				45				63				72				64				64				56				55				44	60

TABLE 3.—*Summer rainfall at Dubuque, Iowa, as related to wind direction, state of weather, barometric height, and barometric tendency. Based on observations at 7 a. m., ninetieth meridian time, for May, June, July, and August, for the years 1889 to 1920, inclusive, except 1894 and 1895*—Continued.

BAROMETER RISING.

	N.				NE.				E.				SE.				S.				SW.				W.				NW.				Total barometer rising.	Grand total.
	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.	Clear.	Partly cloudy.	Cloudy.	Total.		
BAROMETER 29.94 INCHES AND UNDER (REDUCED TO SEA LEVEL).																																		
Total	12	15	18	45	1	2	7	10	1	2	3	6	13	6	14	33	16	11	13	40	26	11	12	49	12	7	21	40	45	21	46	112	335	1,042
Rain in 12 hours:																																		
Number	4	2	9	15	0	1	2	3	0	0	1	1	0	0	8	8	5	7	6	18	7	4	6	17	0	1	10	11	12	5	18	35	108	503
Expected number				14.5				3.2				1.9				10.6				12.9				15.8				12.9				36.1		
Per cent				33				30				17				24				45	27			35			48	28	27	24	39	31	32	48
Rain in 24 hours:																																		
Number	5	2	10	17	0	1	3	4	1	1	1	3	4	4	13	21	9	9	10	28	12	8	11	31	5	2	12	19	16	5	25	46	169	654
Expected number				22.7				5.0				3.0				16.6				20.2				24.7				20.2				56.5		
Per cent				38				40				50				64				70	46			63			57	48	36	24	54	41	50	63
BAROMETER 29.95 TO 30.04 INCHES (REDUCED TO SEA LEVEL).																																		
Total	27	14	20	61	11	4	20	35	9	3	17	29	29	11	12	52	20	9	14	43	23	8	10	41	18	5	5	28	80	17	26	123	412	883
Rain in 12 hours:																																		
Number	2	2	9	13	0	0	10	10	2	0	7	9	8	4	7	19	3	3	9	15	5	2	4	11	2	1	2	5	4	5	9	18	100	297
Expected number				14.8				8.5				7.0				12.6				10.4				10.0				6.8				29.9		
Per cent	7		45	21			50	29				31	28			37	15			35	22			27				18	5		35	15	24	34
Rain in 24 hours:																																		
Number	4	5	11	20	1	1	11	13	2	2	11	15	11	5	8	27	7	4	11	22	10	4	7	21	5	1	3	9	11	7	9	27	151	416
Expected number				22.4				12.8				10.6				19.1				15.8				15.0				10.3				45.1		
Per cent	15		55	33			55	37				52	38			46	35			51	43			51				32	14		35	22	37	47
BAROMETER 30.05 TO 30.14 INCHES (REDUCED TO SEA LEVEL).																																		
Total	41	11	19	71	33	10	18	61	18	10	15	43	47	18	21	86	24	7	14	45	14	2	9	25	11	8	7	26	98	25	21	144	501	807
Rain in 12 hours:																																		
Number	4	2	4	10	2	2	9	13	0	1	8	9	4	4	11	19	0	1	7	8	2	0	5	7	2	2	2	6	5	5	7	17	89	198
Expected number				12.6				10.8				7.6				15.3				8.0				4.4				4.6				25.6		
Per cent	10			14	6			21				21	9		52	22	0			18				28				23	5	20	33	12	18	25
Rain in 24 hours:																																		
Number	6	4	5	15	4	5	11	20	2	2	10	14	10	10	15	35	4	4	8	16	3	1	7	11	2	2	2	6	20	9	8	37	154	314
Expected number				21.8				18.7				13.2				26.4				13.8				7.7				8.0				44.2		
Per cent	15			21	12			33				33	21		71	41	17			36				44				23	20	36	38	26	31	39
BAROMETER 30.15 INCHES AND OVER (REDUCED TO SEA LEVEL).																																		
Total	73	9	16	98	40	18	20	78	30	18	16	64	68	13	23	104	22	2	9	33	13	3	4	20	11	2	2	15	62	9	16	87	499	658
Rain in 12 hours:																																		
Number	0	1	7	8	0	1	7	8	0	3	5	8	3	2	7	12	0	0	6	6	2	0	1	3	0	0	1	1	1	3	5	9	55	104
Expected number				10.8				8.6				7.0				11.4				3.6				2.2				1.6				9.6		
Per cent	0			8	0		35	10	0			12	4		30	12	0			18				15				7	2			10	11	16
Rain in 24 hours:																																		
Number	9	3	8	20	3	4	10	17	5	9	7	21	13	3	9	25	3	0	7	10	2	0	1	3	4	1	1	6	10	4	6	20	122	193
Expected number				23.9				19.0				15.6				25.4				8.1				4.9				3.7				21.2		
Per cent	12			20	8		50	22	17			33	19		39	24	14			30				15				40	16			23	24	29
Totals:																																		
Total				275				184				142				275				161				135				109				466	1,747	3,390
Rain in 12 hours:																																		
Number				46				34				27				58				47				38				23				79	352	1,102
Expected number				55.4				37.1				28.6				55.4				32.4				27.2				22.0				93.9		
Per cent				17				18				19				21				29				28				21				17	20	33
Rain in 24 hours:																																		
Number				72				54				53				105				76				66				40				130	596	1,577
Expected number				93.8				62.8				47.4				93.8				54.9				46.1				37.2				159.0		
Per cent				26				29				37				38				47				49				37				28	34	47

TABLE 4.—*Summer rainfall at Dubuque, Iowa, as related to kind and amount of cloudiness, and to barometric height and barometric tendency—Based on observations at 7 a. m., 90th meridian time, for May, June, July, and August, for the years 1889 to 1920, inclusive, except 1894 and 1895.*

BAROMETER FALLING.

	Ci.				Ci.St.				Ci.Cu.				A.St.				A.Cu.				St.Cu.				Cu.				St				Dense fog.	No clouds (including few and light fog).	Total, barometer falling.
	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.			
BAROMETER 29.94 INCHES AND UNDER (REDUCED TO SEA LEVEL).																																			
Total	31	8	0	39	69	35	5	109	11	2	0	13	46	30	23	99	25	13	0	38	16	29	46	91	30	10	4	44	40	37	200	277	9	77	796
Rain in 12 hours:																																			
Number	16	4	0	20	26	19	3	48	3	0	0	3	22	12	14	48	12	7	0	19	6	17	34	57	11	2	1	14	14	19	131	164	5	16	304
Expected number				19.3				54.0				6.4				49.0				18.8				45.0				21.8				137.1	4.5	38.1	
Per cent	52			51	38	54		44				23	48	40	61	48	48			50		59	74	63	37			32	35	51	66	59	56	21	49
Rain in 24 hours:																																			
Number	18	7	0	25	39	24	5	68	8	0	0	8	29	18	16	63	46	11	0	27	8	19	38	65	13	5	1	19	26	24	148	198	7	34	514
Expected number				25.2				70.4				8.4				64.0				24.5				58.8				28.4				178.9	5.8	49.7	
Per cent	58			64	57	69		62				62	63	60	70	64	64			71		66	83	71	43			43	65	65	74	71	78	44	65
BAROMETER 29.95 TO 30.04 INCHES (REDUCED TO SEA LEVEL).											4																								
Total	34	7	2	43	38	34	1	73	7	3	0	10	35	24	15	74	15	6	2	23	11	18	28	57	24	5	3	32	25	17	97	139	3	82	536
Rain in 12 hours:																																			
Number	8	2	1	11	11	11	0	22	1	1	0	2	15	9	12	36	6	0	0	6	8	6	14	28	9	1	0	10	5	10	55	70	0	11	196
Expected number				15.7				26.7				3.7				27.1				8.4				20.9				11.7				50.9	1.1	30.0	
Per cent	24			26	29	32		30				20	43	38		49				26			50	49	38			31	20		57	50	0	13	37
Rain in 24 hours:																																			
Number	17	6	1	24	18	17	0	35	4	3	0	7	24	12	12	48	7	0	1	8	9	7	19	35	15	2	0	17	11	11	69	91	0	23	288
Expected number				23.1				39.2				5.4				39.7				12.4				30.6				17.2				74.6	1.6	44.0	
Per cent	50			56	47	50		48				70	69	50		65				35			68	61	62			53	44		71	65	0	28	54
BAROMETER 30.05 TO 30.14 INCHES (REDUCED TO SEA LEVEL).																																			
Total	21	4	0	25	30	16	3	49	11	1	1	13	15	9	10	34	7	6	0	13	10	13	12	35	5	5	3	13	7	12	57	76	3	83	344
Rain in 12 hours:																																			
Number	6	0	0	6	6	5	0	11	3	1	0	4	4	5	3	12	1	4	0	5	2	5	7	14	2	2	1	5	3	5	28	36	0	12	105
Expected number				7.6				14.9				4.0				10.4				4.0				10.7				4.0				23.2	0.9	25.3	
Per cent	29			24	20			22				31				35				38				40				38			49	47	0	14	31
Rain in 24 hours:																																			
Number	7	2	0	9	11	11	0	22	6	1	0	7	8	8	5	21	2	4	0	6	3	8	9	20	2	3	1	6	5	8	38	51	0	25	167
Expected number				12.1				23.8				6.3				16.5				6.3				17.0				6.3				36.9	1.5	40.2	
Per cent	33			36	37			45				54				62				46				57				46			67	67	0	30	49
BAROMETER 30.15 INCHES AND OVER (REDUCED TO SEA LEVEL).																																			
Total	11	1	0	12	24	11	2	37	3	1	0	4	7	5	10	22	7	7	0	14	3	1	6	10	0	2	2	4	7	4	20	31	2	52	188
Rain in 12 hours:																																			
Number	2	1	0	3	8	2	1	11	1	1	0	2	3	1	6	10	2	4	0	6	0	1	2	3	0	0	1	1	5	1	11	17	0	4	57
Expected number				3.6				11.2				1.2				6.7				4.2				3.0				1.2				9.4	0.6	15.8	
Per cent				25	33			30				50				45				43				30				25			55	55	0	8	30
Rain in 24 hours:																																			
Number	4	1	0	5	15	6	1	22	2	1	0	3	3	3	7	13	4	6	0	10	1	1	3	5	0	0	2	2	5	1	13	19	0	8	87
Expected number				5.6				17.1				1.9				10.2				6.5				4.6				1.9				14.4	0.9	24.1	
Per cent				42	62			59				75				59				71				50				50			65	61	0	15	46
Totals:																																			
Total				119				268				40				229				88				193				93				523	17	294	1,864
Rain in 12 hours:																																			
Number				40				92				11				106				36				102				30				287	5	43	752
Expected number				48.0				108.0				16.1				92.3				35.5				77.8				37.5				210.8	6.8	118.5	
Per cent				34				34				28				46				41				53				32				55	29	15	40
Rain in 24 hours:																																			
Number				63				147				25				145				51				125				44				359	7	90	1,056
Expected number				67.5				152.0				22.7				129.8				49.9				109.4				52.7				296.5	9.7	166.7	
Per cent				53				55				62				63				58				65				47				69	41	31	57

TABLE 4.—*Summer rainfall at Dubuque, Iowa, as related to kind and amount of cloudiness, and to barometic height and barometic tendency—Based on observations at 7 a. m., 90th meridian time, for May, June, July, and August, for the years 1889 to 1920, inclusive, except 1894 and 1895—* Continued.

BAROMETER RISING.

	Ci.				Ci.St.				Ci.Cu.				A.St.				A.Cu.				St.Cu.				Cu.				St.				Dense fog.	No clouds (including "few" and light fog).	Total, barometer rising.	Grand total.
	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.	1-3	4-7	8-10	Total.				
BAROMETER 29.94 INCHES AND UNDER (REDUCED TO EA LEVEL).																																				
Total	18	4	0	22	30	23	4	57	8	0	0	8	25	13	10	48	10	4	0	14	11	13	9	33	9	3	5	17	16	25	76	117	3	74	393	1,189
Rain in 12 hours:																																				
Number	4	1	0	5	5	5	2	12	0	0	0	0	5	6	2	13	5	0	0	5	5	4	7	16	1	1	1	3	8	10	33	51	2	13	120	514
Expected number				6.7				17.4				2.4				14.6				4.3				10.1				5.2				35.7	0.9	22.6		
Per cent				23	17	22		21				0	20			27				36				48				18		40	43	44	67	18	31	43
Rain in 24 hours:																																				
Number	9	2	0	11	13	8	3	24	0	0	0	0	5	9	5	19	7	1	0	8	7	6	7	20	5	2	2	9	10	12	47	69	3	27	190	704
Expected number				10.6				27.5				3.9				23.2				6.8				15.9				8.2				56.5	1.4	35.7		
Per cent				50	43	35		41				0	20			40				57				61				53		48	62	59	100	36	48	59
BAROMETER 19.95 TO 30.04 INCHES (REDUCED TO SEA LEVEL).																																				
Total	28	4	1	33	53	28	4	85	3	4	0	7	26	15	9	50	11	5	1	17	15	8	13	36	10	2	2	14	20	14	60	94	9	123	468	1,004
Rain in 12 hours:																																				
Number	6	0	0	6	10	7	0	17	1	1	0	2	6	6	[illegible]	16	3	1	1	5	4	3	4	11	2	0	0	2	5	8	25	38	2	12	111	307
Expected number				7.8				20.1				1.7				11.8				4.0				8.5				3.3				22.3	2.1	29.2		
Per cent	21			18	19	25		20				29	23			32				29				31				14	25		42	40	22	10	24	31
Rain in 24 hours:																																				
Number	11	1	0	12	24	11	2	37	1	1	0	2	10	7	6	23	4	3	1	8	5	4	5	14	4	1	0	5	7	11	31	49	2	23	175	463
Expected number				12.3				31.8				2.6				18.7				6.4				15.5				5.2				35.2	3.4	46.0		
Per cent	39			36	45	39		44				29	38			46				47				39				36	35		52	52	22	19	37	46
BAROMETER 30.05 TO 30.14 INCHES (REDUCED TO SEA LEVEL).																																				
Total	38	4	0	42	52	42	3	97	16	2	0	18	23	11	14	48	15	5	1	21	10	14	12	36	9	3	4	16	21	17	60	98	8	192	576	920
Rain in 12 hours:																																				
Number	7	0	0	7	8	7	0	15	2	2	0	4	6	2	6	14	4	3	1	8	2	4	6	12	2	0	0	2	1	6	19	26	2	9	99	204
Expected number				7.2				16.7				3.1				8.3				3.6				6.2				2.8				16.9	1.4	33.0		
Per cent	18			17	15	17		15				22	26			29				38				33				12	5		32	27	25	5	17	22
Rain in 24 hours:																																				
Number	13	0	0	13	15	21	1	37	4	2	0	6	6	4	8	18	6	4	1	11	3	5	8	16	5	0	1	6	4	9	26	39	2	20	177	344
Expected number				12.9				29.8				5.5				14.7				6.4				11.1				4.9				30.1	2.5	58.9		
Per cent	34			31	29	50		38				33	26			38				52				44				38	19		43	40	25	15	31	37
BAROMETER 30.15 INCHE AND OVER (REDUCED TO EA LEVEL).																																				
Total	45	8	0	53	58	40	3	101	11	3	0	14	19	13	9	41	18	7	2	27	14	5	14	33	4	2	1	7	16	7	46	69	11	225	581	769
Rain in 12 hours:																																				
Number	1	0	0	1	4	6	2	12	1	1	0	2	2	3	4	9	1	3	0	4	5	1	3	9	0	0	0	0	2	1	18	21	1	3	62	119
Expected number				5.7				10.8				1.5				4.4				2.9				3.5				0.7				7.4	1.2	24.1		
Per cent	2			2	7	15		12				14				22				15				27				0			39	30	10	1	11	16
Rain in 24 hours:																																				
Number	9	2	0	11	15	10	2	27	3	1	0	4	4	4	5	13	3	5	0	8	7	2	4	13	2	0	0	2	8	3	23	34	1	31	144	231
Expected number				13.2				25.2				3.5				10.2				6.8				8.2				1.8				17.2	2.8	56.2		
Per cent	20			21	26	25		27				29				32				30				39				29			50	49	10	14	25	30
Totals:																																				
Total				150				340				47				187				79				138				54				378	31	614	2,018	3,882
Rain in 12 hours:																																				
Number				19				56				8				52				22				48				7				136	7	37	392	1,144
Expected number				29.1				66.0				9.1				36.3				15.3				26.8				10.5				73.3	9.0	119.1		
Per cent				13				16				17				28				28				35				13				36	23	6	19	29
Rain in 24 hours:																																				
Number				47				125				12				73				35				63				22				191	8	110	686	1,742
Expected number				51.0				115.6				16.0				63.6				26.9				46.9				18.4				128.5	14.0	208.8		
Per cent				31				37				26				39				44				46				41				51	26	18	34	45

THE FIRE-COLORED SUNSET AS A VALUABLE CLUE TO THE EXISTENCE OF A TROPICAL STORM.

By R. M. DOLE, Observer.

[Weather Bureau, Wilmington, N. C., Nov. 26, 1920.]

Wireless has made the location of tropical disturbances fairly certain, but some of small diameter may form in a bend in the isobars or be undiscovered by ships. Therefore hurricane observers must watch every sign during the season, and let nothing escape their notice.

There have been several cases of small tropical storms which appeared without warning, no upper clouds moving from an unusual direction, sea swells or even increase in wind.

However there is an important sign that may indicate the existence of a hurricane when nothing else does, the lurid sunset, which often precedes the sea swell and upper clouds by 24 to 48 hours or more.

As is well known a hurricane has a small, violent center, but it affects the atmosphere for a distance of over a thousand miles, as proved by observations of the clouds, pressure and temperature in the different quadrants. It is not unlike the emptying of a washbowl of water, the center having a violent twist, while the currents on the outside slowly revolve in large circles. The air around a hurricane must behave in a similar manner, and thus spread, the dust forms circularly around the center. Approximately twenty minutes after the sun has gone below the horizon the rays that pass through these dust bands are reflected by the clouds as a fire color. This may also happen before sunrise, as observed during September 1920. The fire color does not last very long and its brilliancy seems to depend on the strength of the disturbance. If there are no clouds present this unusual color can not be detected, which may explain why no lurid sunsets were seen before several of the famous hurricanes, the sky either being devoid of clouds, or the observer did not look at the right time.

The fire-colored sunset is quite different from the ordinary colored sunset, being awe-inspiring and apparent to even a layman if he happens to look up at the right time.

This clue is especially valuable in showing the presence of small hurricanes which have not been discovered. Such a warning sunset was observed on different evenings during the period from September 17 to 21 at Wilmington, N. C. Although there was a tropical storm in the Gulf, still the lurid sunsets combined with unusual directions of the cirrus, moving from south and southeast made the observers on duty suspicious of another off the south Atlantic coast.

The cirri during September 17 to 21 were moving at a variable rate from a southerly direction, but they always melted as they came in from the sea, apparently indicating that the disturbance was of such small vertical extent that the outflowing clouds from it could not last long in the slowly descending air of the anticyclone then establishing itself over the south Atlantic States. September 20 and 21 the wind was fresh northeast, rather gusty, a suspicious sign. Before sunrise and sunset on the 21st the fire color was noticed even by people on the street. Unusual cloud formations with the fire color reflected from them on the morning of September 22 gave a premonition of a small but severe storm outside and coming towards the station. The cirrus was from the southeast and the alto-stratus from the east, while other different types of clouds were moving from other directions. There were three different kinds of cirro-cumulus moving at three different heights with the directions and the rate of translation all different. A typical hurricane sky of the mackerel variety presented itself. These warnings proved correct, for between 6 and 7 p. m. the wind reached a velocity of 33 miles an hour as measured by the station anemometer, an estimated rate of 60 miles at the beach where it blew down a house and 90 miles outside as reported by dependable ship captains. It was accompanied by strong squalls and heavy downpours. Shortly after, there was a lull, and the sky became clear, followed by a strong southeast wind and air that felt hot as if from an oven, the temperature being 77° or more all night and the humidity high. The sea ran heavily at the beach and ships outside reported a small, but severe storm. The pressure showed only a slight dip, not enough to give any evidence of the presence of such a disturbance.

Bright-colored sunsets and sunrises occur at any time of year and are due to a variety of causes, such as volcanic dust, approaching circular storms, cold waves, warm waves and have been observed when there seemed to be no explanation, but a typical fire-colored sunrise or sunset during the hurricane season below the 35th parallel of latitude may be an important warning, especially when combined with other signs, such as clouds moving from an unusual direction, increase in suspicious wind directions (northeast, north and east), sea swells and even when there is no particular fall in pressure. It may be the only clue to the dangerous tropical storms of small diameter which form in a bend in the isobars, over the Gulf Stream or are offshoots of larger hurricanes. The observing of the fire color must put any observer on his guard during the season when the beaches are crowded with visitors, because beaches are epescially exposed, there are often no good harbors, and the available means of carrying people to safety are limited. To allow a hurricane to appear unheralded might mean a serious loss of life.

THE "TABLECLOTH" OF TABLE MOUNTAIN.

By C. FITZHUGH TALMAN, Librarian.

[U. S. Weather Bureau, Washington, D. C., March, 1921.]

We are indebted to Mr. W. T. Crespinel, of Prizma (Inc.), New York, City for permission to publish the accompanying photograph (Fig. 1) of the celebrated "Tablecloth," capping the summit of Table Mountain, South Africa.[1]

A rather hasty search on the part of the writer has brought to light only three pictures of the Tablecloth, in addition to Mr. Crespinel's photograph and apart from mere diagrams illustrating the process of the cloud's formation. Two of these pictures are reproduced herewith. A third, published in the report of the "Valdivia" Expedition of 1898–99, is reproduced in F. Ratzel's "Die Erde," vol. 2, p. 477.

The literature of the Tablecloth dates back at least as far as the seventeenth century. One of the pictures here shown (fig. 2) is taken from the curious treatise by Erasmus Francisci entitled "Der Wunder-reiche Überzug unserer Nider-Welt, oder Erd-umgebende Luft-Kreys," etc., published at Nürnberg in 1680. A quaint description of the phenomenon, found in the same work, may be freely translated as follows:

"Not far from the shore stands a large mountain, which does not taper to the summit, but is flat on top like a table; whence the Netherlanders call it Table Mountain. From this summit the flying storm often breaks forth with fury, after having announced itself by a certain sign. For, when the sky is clearest and the sea most tranquil, there may be seen over the mountain a delicate little cloud, which at first seems hardly so big as a barley-corn, and then the size of a walnut; wherefore the Portuguese and Hollanders call this cloud, which is barely visible at a distance, the 'bull's-eye.' At once it grows and spreads over the whole top of the mountain, and then the Hollanders say, 'The table is spread,' because, as they declare, the appearance is as if a table were spread and set with all kinds of food. Immediately afterward the cloud-storm comes sweeping down from the summit with such violence that unless ships are heedful in good time to shorten sail they are all dashed to the bottom."

The best known scientific description of the Tablecloth is that given in Sir John F. W. Herschel's "Meteorology" (Edinburgh, 1861):

"That the mere self-expansion of the ascending air is sufficient to cause precipitation of some of its vapour, when abundant, is rendered matter of ocular demonstration in that very striking phenomenon so common at the Cape of Good Hope, where the south or south-easterly wind which sweeps over the Southern Ocean, impinging on the long range of rocks which terminate in the Table Mountain, is thrown up by them, makes a clear sweep over the flat table-land which forms the summit of that mountain (about 3,850 feet high), and thence plunges down with the violence of a cataract, clinging close to the mural precipices that form a kind of background to Cape Town, which it fills with dust and uproar. A perfectly cloudless sky meanwhile prevails over the town, the sea, and the level country, but the mountain is covered with a dense white cloud reaching to no great height above its summit, and quite level, which, though evidently swept along by the wind, and hurried furiously over the edge of the precipice, dissolves and completely disappears on a definite level, suggesting the idea (whence it derives its name) of a 'Tablecloth.' Occasionally when the wind is very violent, a ripple is formed in the aerial current, which, by a sort of rebound in the hollow of the amphitheatre in which Cape Town stands, is again thrown up, just over the edge of the sea, vertically over the Jetty, where we have stood for hours watching a small white patch of cloud in the zenith, a few acres in extent, in violent internal agitation (from the hurricane of wind blowing through it), yet immovable, as if fixed by some spell, the material ever changing, the form and aspect unvarying. The Tablecloth is formed also at the commencement of a 'north-wester,' but its fringes then descend on the opposite side of the mountain, which is no less precipitous."

An example of this alternative variety of the cloud, due to a "northwester," is illustrated in Herschel's book, and we have reproduced his picture (fig. 3), which shows a flat sheet of cloud corresponding much more closely to the idea suggested by the name "Tablecloth" than do the clouds seen in the other two pictures herewith.

From the "Guide to South Africa," by A. S. and G. G. Brown, numerous editions of which have been published by the Union-Castle Mail Steamship Co., it appears that the Tablecloth, on account of the suddenness of its formation, is a source of danger to persons who climb the mountain. We quote from the sixteenth edition (London, 1909):

"The ascent of Table Mountain, although fatiguing, offers no mountaineering difficulties. The only danger to be apprehended is from the dense clouds which collect at times round the summit of the mountain and produce the well-known phenomenon of the Tablecloth. As this peculiar appearance is generally occasioned by southeast winds, it occurs more frequently in summer than in winter, but the extreme suddenness with which the clouds arrive makes it impossible at any time to predict that the mountain will be clear for the next 24 hours. Fatal accidents have occurred from visitors wandering about in the mist and falling over precipices, whilst others, preferring the safer plan of waiting for the mist to rise, have remained in one spot for many hours."

The Tablecloth is of further interest to meteorologists as affording a well-known example of the phenomenon of fog-drip. During the almost rainless summers of this region, the upper parts of Table Mountain, as well as of other mountains of the Cape, are clad in a luxuriant vegetation, supported by a copious deposit of moisture from the drifting clouds. Measurements of the fog-drip on Table Mountain have been made by Dr. R. Marloth, who has published his results in the *Transactions of the South African Philosophical Society*, v. 14, 1903, p. 403–408, and v. 16, 1905, p. 97–105. See also a discussion of these investigations in *Meteorologische Zeitschrift*, v. 23, 1906, p. 547–553.

[1] Published on a large scale in *New York Evening Post*, Oct. 2, 1920, pt. 5, p. 1.

FIG. 1.—The "Tablecloth," capping the summit of Table Mountain, South Africa.
(Photograph by W. T. Crespinel (copyrighted).)

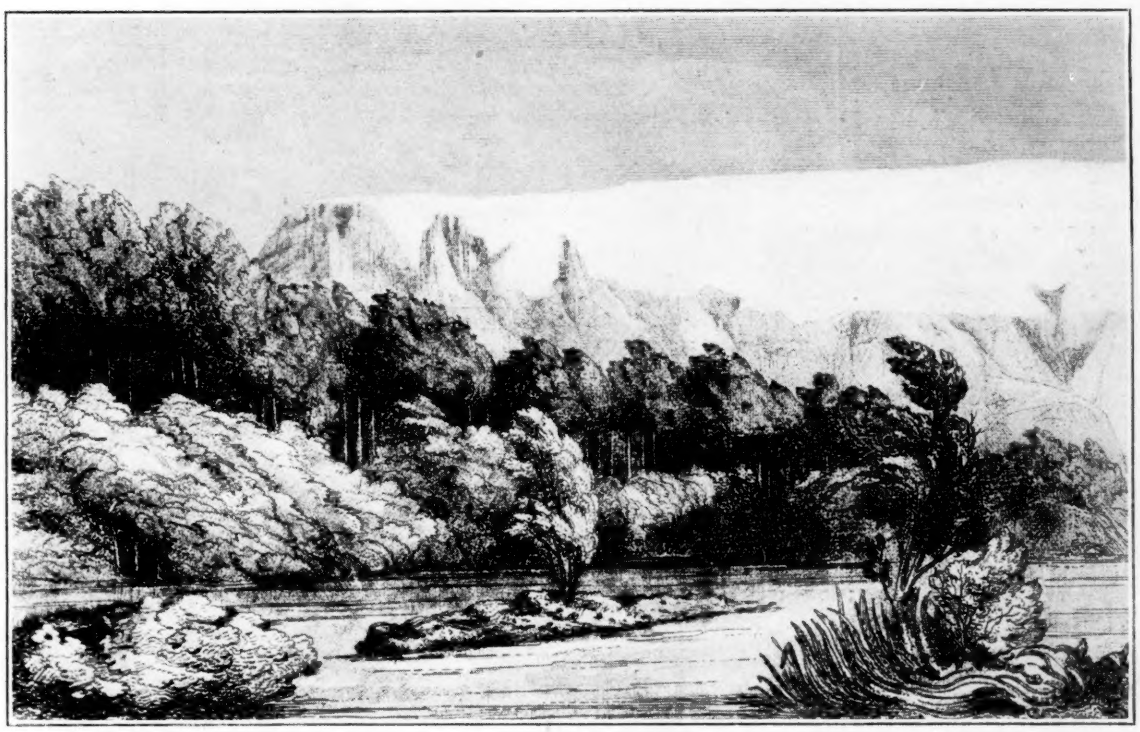


FIG. 3.—The "Tablecloth" formed by a "northwester." (From Herschel's "Meteorology," 1861.)

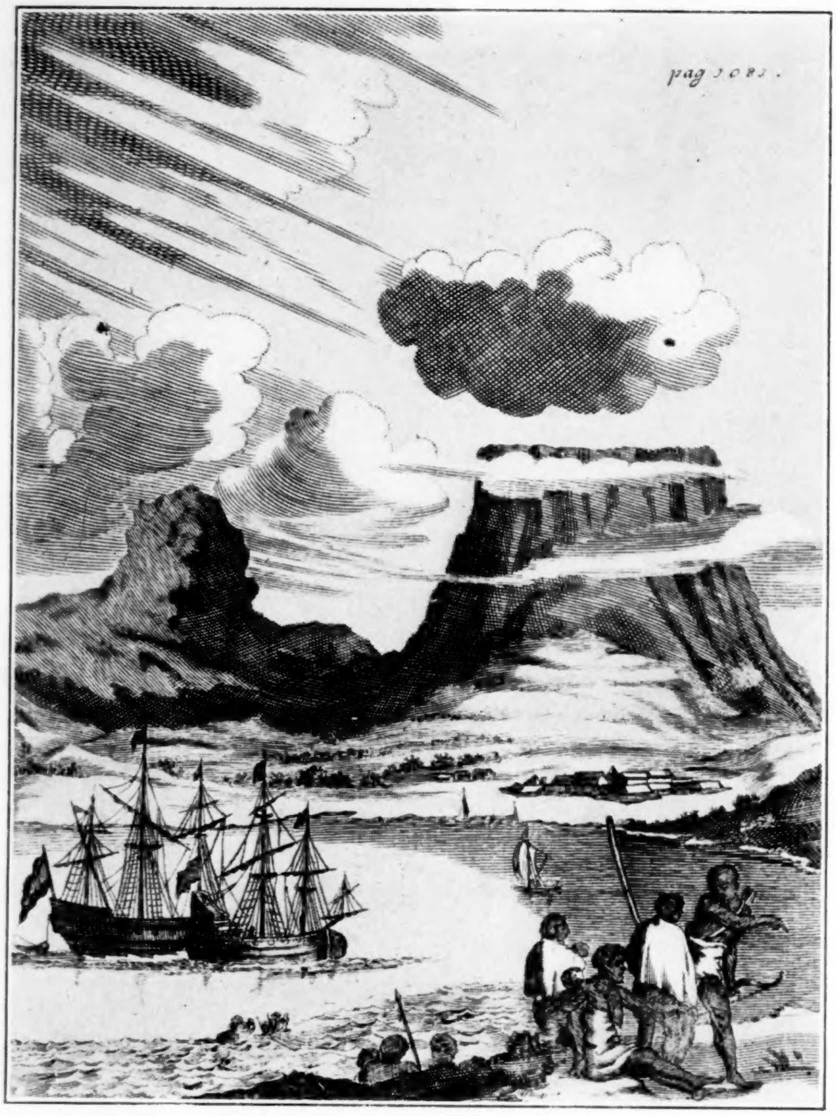


FIG. 2.—The "Tablecloth." (From a picture published by E. Francisci, 1680.)

FIG. 4.—A cloud draping Mount Shasta, California. (Reproduced by permission of Earl N. Findley, editor, *U. S. Air Service* (October, 1920, p. 14).)

THUNDERSTORM-BREEDING SPOTS.

By ROBERT E. HORTON.

[Voorheesville, N. Y., October, 1920.]

It appears probable that under even favorable conditions as regards the cyclonic circulation, thunderstorms only develop from convective puffs of ascending air, when the violence of the ascending current exceeds some minimum limit corresponding to the weather conditions overhead for the day. It may happen that local conditions in a certain place will induce convective activity of sufficient strength to produce thunderstorms day after day, whereas at a near-by locality only a few miles distant only cumulus clouds will develop. An appropriate name for these spots where thunderstorms may be bred in large numbers is wanting, and so they may merely be called "thunderstorm-breeding spots." Very likely such spots are numerous, and could be quite accurately and permanently mapped with sufficient data. General observation indicates some locations where they may occur. For example, some cities, if not indeed most inland cities of say 100,000 population or more, appear to be thunderstorm spots.

The writer has observed some thunderstorms over some cities, for example, Albany, N. Y., and Providence, R. I., which originated immediately over the city and did not travel far outside their limits on days when there were no other adjacent thunderstorms. Again a shallow lake with sandy margins located in a forest may serve as a thunderstorm breeder. The writer has observed thunderstorms originating near the westerly end of Oneida Lake, traveling eastward about 18 miles, the length of the lake, and then dying out soon after reaching the easterly shore, on days when there were no thunderstorms in the surrounding country. Oneida Lake is about 5 miles wide and 18 miles long, located in a flat and generally wooded region and has warm, shallow waters and sandy shores. The water and sand of the lake become much warmer than the surrounding air, especially warmer than that in the woods on summer afternoons.

Capt. Harry Barker describes a number of occurrences of thunderstorms in the Grand Canyon of the Colorado. The air in the bottom of the Canyon became intensely overheated, and apparently rose to condensation level, which was below the rim, so that the thunderstorm with vivid playing of the lighting could be observed from the top of the Canyon rim, looking over the clouds to the opposite margin of the Canyon, which was clear.

Some western arroyos are notable for the frequency of occurrence of so-called cloudburst thunderstorms. Statistics are not available, but general reports seem to indicate that such storms occur more often on some arroyos than on others adjacent to them. The conditions of occurrence of thunderstorms in the Grand Canyon, and the conditions favoring thunderstorm-breeding spots, suggest that possibly some arroyos, or their drainage areas may be so situated as to form very favorable breeding spots for thunderstorms.

The facility of this operation may be affected by orientation and isolation, so that one arroyo basin might be a frequent starting point for thunderstorms, whereas another adjacent to it might rarely produce them. While this point is as yet purely hypothetical, it is worthy of further study, since a tendency to the frequent occurrence of thunderstorms in certain arroyo basins or on their headwater plateaus more often than on those adjacent, might be a very important factor affecting the design of dams such as are commonly located in these canyons for irrigation and other purposes.

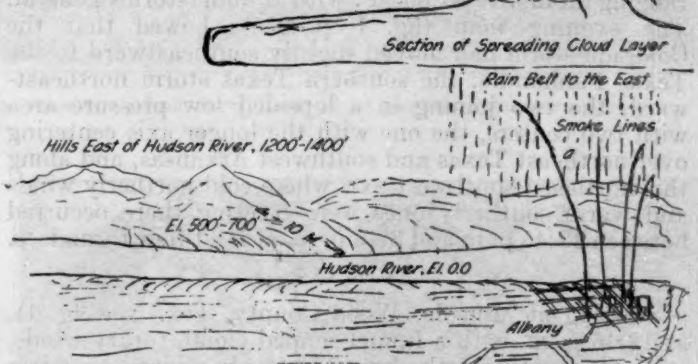
If it is true, as the writer believes, that certain places are exceedingly favorable to the generation of thunderstorms, then it appears to be a matter worthy of careful study. An indication of the truth of the supposition that cities breed thunderstorms might be obtained by comparison of rain gages in the surrounding country with records taken in the city during the thunderstorm months. Records of the number of thunderstorms taken in large cities are probably not sufficiently accurate to afford a reliable basis of comparison with thunderstorm frequency in the immediate surrounding country. Should it prove true that cities are in some instances thunderstorm breeders, whereas other near-by cities may not possess this characteristic, then such facts might have a very important bearing on various engineering problems, notably storm-sewer design, and might vitiate the utility of application of records of thunderstorm rain intensities in one city to another near-by city, even though the climate of the two places and the total rainfall per annum might be very nearly the same.

THE BEGINNING OF A THUNDERSTORM.

By ROBERT E. HORTON.

[Voorheesville, N. Y., August, 1920.]

It is not often that one can watch the inception of a local thunderstorm. Such an opportunity occurred to the writer on the afternoon of July 26, 1920. The



morning weather map showed an enormous high, prevailing generally over central New York, with isobar 30.1 at Albany. The writer was in the city of Albany during the afternoon. The sky was generally clear between 2 and 5 p. m., with occasional flat-bottom fair-weather clouds. Coming out of a building at 5 p. m., and starting westward by automobile, I noticed a layer of dark clouds directly overhead and heard thunder nearby to the east.

Within a few minutes, and at a time when I was about 1 mile west of the city, thunder became more violent. I noticed the cloud layer spreading rapidly in all directions, and there was a violent rush of cold wind from the west, followed within a few moments by a sprinkle of large raindrops. In the lower part of the city smoke was issuing freely from several power-plant and factory chimneys, and the course of the smoke leaving these chimneys in relation to the overlying cloud layer was something, as shown by the accompanying sketch. One smoke column, marked "A" in the sketch, in particular rose in a graceful parabolic line to a height apparently of 1,500 to 2,500 feet.

One can imagine the air near the surface becoming overheated during the afternoon, rushing upward, and spreading out at the cloud level, the upward course being marked roughly by the lines of smoke and the whole mass of air forming a solid shape very much like a flat-topped mushroom. The sky was generally clear, and I encountered no rain in traveling 10 miles west of Albany.

During this trip I could look back eastward across the Hudson Valley and could see the back of a thunderstorm traveling eastward. The width of the rain belt was apparently not over 2 or 3 miles, judged from the known locations of adjacent hills.

After arriving at my home, and at least one hour after the storm started, at a time when the sky overhead was bright and clear, a sprinkle of large raindrops fell. The sky was clear from clouds everywhere, except far to the east, and it would appear that these raindrops may have been formed with the first uprush of air at Albany and had been slowly drifting westward with an upper air current, or with the spreading out of the mushroom top of the convective air column, finally being precipitated at least 9 miles from their place of origin.

TORNADOES OF APRIL 15, 1921, IN ARKANSAS AND TEXAS.

By W. C. Hickmon, Observer.

[Weather Bureau, Little Rock, Ark., Apr. 28, 1921.]

SYNOPSIS.

During the afternoon and evening of April 15, 1921, four tornadoes occurred in Arkansas and Texas. The most destructive of these started in Texas, but most of the damage done by it was in Arkansas, so the Texas end of the path is discussed briefly in connection with the Arkansas storms. Fifty-six people were killed in these four tornadoes, and the property loss is estimated at about $1,300,000.

PRECEDING AND ATTENDING WEATHER.

The morning weather map of April 15 showed high pressure over the central Canadian Provinces, a storm of marked intensity centered over southeastern Colorado, and moderate disturbances over the lower lakes and extreme southern Texas. Temperatures had risen during the preceding 24 hours throughout the South but from the upper lakes westward cooler weather prevailed. The 15th was a sultry day in Arkansas, the sky overcast most of the time, the humidity high, the maximum temperatures at stations in the southern half of the State ranging from 70° to 80° F. with thunderstorms general. The evening map (fig. 1, p. 255), showed that the Colorado storm had moved slightly southeastward to the Texas Panhandle, the southern Texas storm northeastward, the two joining in a lopsided low pressure area with two centers, the one with the longer axis centering over northeast Texas and southwest Arkansas, and along this northeast-southwest axis where cold northerly winds and warm southerly ones were meeting there occurred between 12:45 p. m and 8:45 p. m. at least four tornadoes.

IN TEXAS.

Starting at Mineola, Wood County, Tex. (see fig. 1), at 12:45 p. m. with a funnel-shaped cloud, rotary winds, and a destructive path about 100 feet in width, the storm moved northeastward increasing in intensity and size, its path at Avinger, Cass County, at 2:30 p. m. varying from 400 to 600 yards in width. Here 8 people were killed, 14 seriously injured, and 30 slightly hurt. Continuing northeastward across the southeast corner of Bowie County, where two people were killed, the tornado crossed the Arkansas-Texas line at a point 8 miles south of Texarkana about 4 p. m.

IN ARKANSAS.

Miller County.—Continuing its northeastward movement the storm struck the Trigenta community where four people were killed. At Shiloh, 7 miles east of Texarkana, two lives were lost and the schoolhouse in which Miss Lena Owens, home demonstration agent, was conducting a club meeting, collapsed on the 15 members, all escaping serious injury.

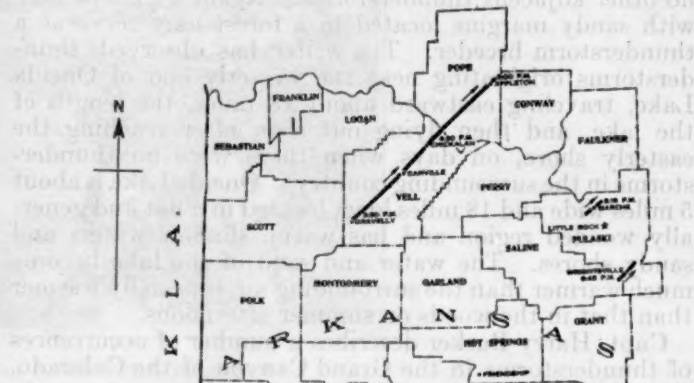


Fig. 1.—Map of northeast Texas and southwest Arkansas showing tracks of tornadoes, Apr. 15, 1921.

On the Boyce, Sims, and Potter plantations, about 3 miles further northeastward, farm buildings and Negro tenant houses were sucked from their moorings and deposited over the countryside, 10 people being killed. Moving on from these plantations the tornado crossed Red River into Hempstead County at Buzzards Bluff.

FIG. 3.—Home of A. J. Brooks on Prescott-Blevins highway, 4 miles south of Blevins, Ark., in which Brooks, his wife, and 11 children were imprisoned though none seriously injured; occupants lay on floor between two beds and the beds held walls off them.

FIG. 4.—Remains of Thebe Shackelford house, near Marlbrook church, carried 200 yards; scattered over a 15-acre field; 5 occupants killed.

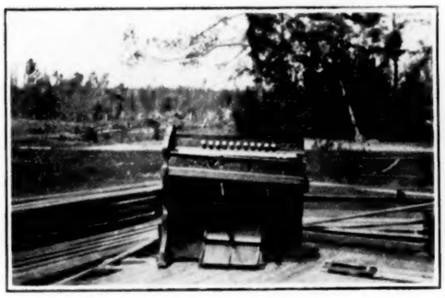


FIG. 2.—Remains of church near Blevins, Ark., after tornado of Apr. 15, 1921.

FIG. 6.—Ford car of Thebe Shackelford partially buried in the ground after having been blown 200 yards.

FIG. 5.—Concrete fireplace base, 3 by 6 feet, moved 3 feet by tornado (Thebe Shackelford house).

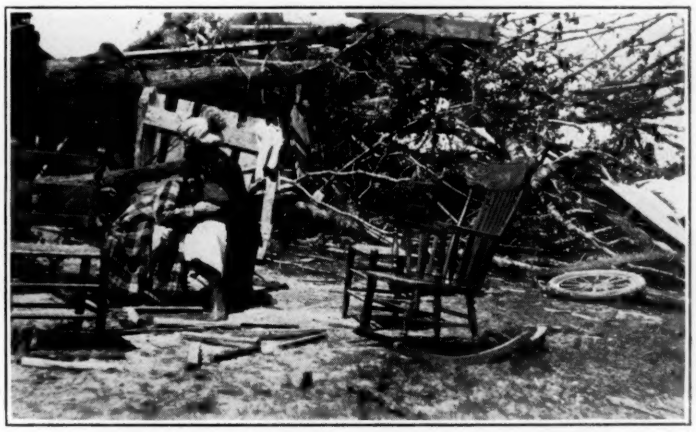


FIG. 7.—Remains of Cullen home near Blevins after tornado of Apr. 15, 1921.

Texarkana was visited during the period of the storm, about 30 minutes, by a heavy fall of rain and hail, the precipitation totaling 2.18 inches. Preceding the heaviest rainfall the air was filled with flying pieces of timber, leaves, and many other articles that had evidently been carried far from where they were first caught up. The occurrence of hail seems to have been confined principally to the west side of the storm, Columbus, Hempstead County, 11 miles northwest of the center of the track, reports that it was in the edge of the region where light hail fell, but that for a distance of 3 to 4 miles on the west side the hail was heavy. The storm was followed by a decided drop in temperature and a chilly night, so many of the injured, who were not found until the morning of the 16th, suffered from a night of exposure.

Along the Ninth Street road leading east from Texarkana, where there is a densely wooded area, massive oaks and pines were twisted off or uprooted and acres of tall trees were laid low, the destructive path through Miller County being about one-third of a mile in width.

Mr. W. S. Sims, a farmer living 10 miles east of Texarkana on the Dooley Ferry road, gives a graphic account of the tornado. He was near his home when he saw a great mass of leaves, timbers, and débris, flying high in the air, and in the distance a terrifying black funnel-shaped cloud moving toward him with a deafening roar. Rushing into his house and shouting to his wife and children to follow him, they ran to a creek about 300 yards distant and crawled under a heavy concrete bridge. A moment later the tornado was upon them and literally pulverized everything above ground in the vicinity. The home they had just left was blown into splinters, but in their place of retreat they escaped unharmed.

Hempstead and Pike Counties.—Leaving Buzzards Bluff and moving rapidly north and a little east to the Missouri Pacific track near Spurdell the storm followed the track by Sheppard, where four Negroes were killed, and on to Guernsey; then turning northward it cut a swath, varying in width from one-fourth to 1½ miles, through the center of Hempstead County. Water Creek Church, Dolph, Jackajones, Marlbrook, and the Wallaceburg communities of Hempstead County were the centers of its fury. Passing out of Hempstead County between sections 29 and 30, Tp. 9 S., R. 23 W., into Pike County, it next struck the Mount Pisgah settlement, near Delight, where 1 person was killed and 24 injured. After passing Pisgah the storm abated, and no further evidence of a twisting storm was found. Several places in Clark County report a "big blow," and at Friendship, just across the Clark County line in Hot Springs County, one home was completely wrecked and two people injured, but the indications are that there was no well-defined tornado. Arkadelphia, Clark County, reports that for several hours on the night of the 15th the atmosphere was kept light enough for reading, due to the incessant flashes of lightning.

The path of destruction through Hempstead County varied from one-fourth to 1½ miles in width, and in it, so far as can be learned, not a house is left standing. Heavy timbers, fences, and all outbuildings were swept before it.

Trees on the north limits of the path fell to the southeast, on the south limits to the northwest, in both cases falling toward the center of the storm path. In the central path of the storm the trees were broken sharply off at varying distances from the ground, only a few apparently blowing down, and these lying in the direction the storm traveled—that is, northeast. The central path of the storm looks like a forest subjected to shell fire.

Sheriff J. M. Dodson, of Hempstead County, was on the Nashville-Hope train en route to Little Rock with ten prisoners when the storm struck the train as it was pulling out from Dolph. Two cars loaded with cotton were blown from the track, the engineer and fireman were blown from the cab, and Engineer Mills declares that the locomotive was partially raised off of the track but settled back without damage. The passenger coach windows were riddled by hail, every house within sight was demolished, and trees 18 inches in diameter were twisted off at the base. No one in the immediate vicinity was killed. Sheriff Dodson described the storm as follows:

> Our first indication of the approaching tornado was seen while we were at the station waiting for the train in Washington. The rain was coming down in a steady downpour. There was an occasional hailstone. It was lightning constantly, one flash following another so rapidly that it appeared to be one flickering sheet of light out in the west, and the thunder didn't let up for an instant. There wasn't even a suggestion of a breeze, but while we were watching, green leaves and small twigs began falling on the station platform. Someone remarked that there was wind high up, and that a storm was passing over.
>
> After the train pulled out of Washington there seemed to be quite a glow over in the west, a glow which rapidly turned to red, like the red of a sunset. Persons around me remarked that it was clearing in the west, that the entire sky would soon be clear. It looked for the world like the clouds were breaking, and the rain had almost stopped.
>
> But as we reached Dolph the clouds seemed to get heavier and darker, and within two or three minutes it became so dark in the coach that one could not see half way down the car. The train started slowly, and I remember I was wondering when the porter would light up, when my thoughts were interrupted by an immense piece of sheet tin slapping the side of the car. The crash combined with the roar of the wind and the train, but within the darkened coach there was no sign of panic. It was as though everybody was stricken with the shock.
>
> It was not until several minutes later when the tornado had passed, and the passengers began piling out of the train, which had stopped when the two freight cars ahead had gone from the track, that the people got excited. Two Negro houses and a barn near the track had been demolished. A crowd of men, women, and children who had been rendered homeless were bunched together, some horrorstricken and quiet and some hysterical, but all too unnerved to begin immediately a search of the débris for possible dead or injured. It was several minutes before a systematic investigation could be started by the passengers and train crew.
>
> Nobody was injured or killed in the houses. No stock was killed, and the mules were found standing just where they had been feeding, though the barn was blown away. The fireman sustained a wrenched back, but was able to continue his run. The engineer had managed to swing by a rod and to climb back into his cab and stop the engine before it had gone more than a short distance. The overturned box cars were clear of the track, and the train was able to resume its trip after a half-hour delay.
>
> A quarter of a mile beyond Dolph the trees were erect, the houses were intact, and there was nothing to indicate that there had been a storm within a hundred miles.

The storm did a number of freakish tricks, some of which were the blowing of ten or a dozen rails from a fence, driving them into the ground and breaking them off, stripping one side of a tree of great limbs, leaving the other untouched, demolishing a church near Blevins, leaving only the organ and Bible (fig. 2). At the home of A. Trapp, 6 miles northwest of Hope, a savings bank was found near the ruins of the house in which there was $4,000, and a large sum was also found on the farm of J. L. Atkins, neatly wrapped in a roll of paper and secured with a rubber band. There was one instance of a man and his family who were sitting on the porch of their home when the tornado struck them. The house was lifted from its foundation and dashed to pieces, but the porch, which was not strongly nailed to the house, remained intact. The family, when the crash came, looked around and saw their home disappear, but none of them had been injured. There were, however, many other freaks telling opposite stories, that is death and destruction to everything near.

Perhaps the greatest catastrophe occurring in Hempstead County was in the little village of Wallaceburg,

2 miles northeast of Blevins. It was here the Thebe Shackelford family lived. Their house was lifted clear of the yard fence and scattered over a 15-acre field (figs. 4 and 5). Furniture was completely destroyed, while the bodies of chickens dotted the ground in the vicinity of the house and barn. A 1920 model Ford car was blown a considerable distance and partially buried in the ground (fig. 6) and the bodies of Mr. and Mrs. Shackelford, two children, and a visitor, were found 100 yards beyond. This house had a concrete foundation, and a concrete base, 3 by 6 feet, on which the fireplace rested, was blown 3 feet from its original position (fig. 5).

Approximately 500 yards north of this scene the home of Mr. Taylor was demolished. Here another miracle was wrought. Mr. Taylor, a man of 80 years, his wife, and their son were the only occupants of the building. Mr. Taylor, a cripple, was unable to help himself. His wife held one door to the room in which they were while the son stood at another. All of the house was blown away with the exception of this room and parts of the porch. The barn close by was completely demolished and feed stuff scattered to the four winds. Several head of stock were killed. None of the three occupants of the house suffered any injuries.

In the A. J. Brooks residence, on the Prescott-Blevins highway 4 miles south of Blevins, Brooks, his wife, and 11 children were imprisoned, though none seriously hurt, when their home was completely demolished. Mr. Brooks says not more than two minutes of time elasped from the time the tornado struck them until it was all over. (Fig. 3.)

A survey of the entire track in Arkansas which is about 70 miles in length, embracing Miller, Hempstead, and a portion of Pike Counties shows the following estimate of damage done and the number killed:

Miller County, killed 16, property damage $175,000.

Hempstead County, killed 34, property damage $1,000,000.

Pike County, killed 1, property damage $50,000.

Table 1 gives information obtained at different points along the path.

Yell-Pope County tornado.—Starting at 3:30 p. m. another smaller and less destructive tornado, moving from the southwest toward the northeast over a path varying in width from 125 to 200 yards, struck Gravelly, Yell County, killing 1 person, injuring 15, and doing property damage estimated at $50,000. Leaving Gravelly the storm rose and passed over Danville too high to do serious damage and struck Chicklah Mountain, which is 800 or 900 feet above the plain, at 4:20 p. m. The top of the mountain is 8 miles long and 2 miles wide and is a rich agricultural section producing large quantities of fruit and potatoes. While there were numerous dwellings demolished and crops were damaged the storm did not have a well-defined path in which everything was destroyed but was more of a straight blow. No further damage was found in Yell County, but continuing in a northeast course into Pope County, 1½ miles northwest of Appleton, further evidence of a tornado is seen. The storm struck here at 5:00 p. m., the path varying in width from 300 yards to one-half mile, the path of greatest destruction being about 200 yards wide. Here 4 people were killed, 6 injured, and property damage to the extent of $10,000 sustained. No further account of damage by this tornado was received.

The Marche tornado.—At 8:18 p. m. on the evening of the 15th a tornado moving from southwest to northeast with a path about one-half mile wide struck Marche, a settlement about 10 miles northwest of Little Rock in Pulaski County. This tornado cut a swath about a mile in length through this settlement, completely destroying seven homes, killing considerable stock and injuring five people, the damage being estimated at $10,000.

Wrightsville tornado.—At Wrightsville, 10 miles southeast of Little Rock in Pulaski County, another tornado with a funnel-shaped cloud, rotary winds, and a path one-quarter mile wide occurred about 8:45 p. m. April 15. This tornado was not so severe as the other three, the destructive path being only 300 feet wide. Damage estimated at $2,500 was sustained, no injury or loss of life being reported.

Tornadoes, Apr. 15, 1921, Arkansas and Texas.

Place.	Time (p. m.).	Direction of movement.	Width of destructive path.	Clouds.	Winds.	Direction trees lay on— N. side.	Direction trees lay on— Center.	Direction trees lay on— S. side.	Killed.	Injured.	Damage estimated.	Remarks.	Information furnished by—
Mineola, Wood County, Tex.	12:45	SW-NE	100 feet	Funnel shaped.	Rotary					1		2 houses destroyed, 6 houses damaged.	Postmaster, Mineola, Tex.
Avinger, Cass County, Tex.	2:50	From 37½° west of S towards 37½° east of N.	400 to 600 yards.	do	do	S.	Twisted mass.	N.	8	44		22 landowners, 16 tenants suffered loss.	Mrs. J. L. Stephenson, secretary Avinger storm-relief committee.
Bowie County, Tex.	3:30	SW-NE	½ mile	do	do	SE	Generally NW.	NE	2				Henry Humphrey, Four State Press, Texarkana, Ark.
Strip 25 miles in length through Miller County, Ark.	4:30	SW-NE	½ mile		Rotary, regular twister.	SE	NE	NW	16	50	$150,000	Damage estimate does not include crop damage.	F. F. Quinn, secretary Red Cross Committee, Texarkana, Ark.
Strip through Hempstead County, about 40 miles.	5:00	SW-NE	¼ to 1½ miles.			NE	NE	NE		[1] 100	1,000,000	Most destructive have ever seen results from.	N. P. O'Neal, Hope, Ark.
2½ to 3 miles southeast of Washington, Hempstead County.	[1] 5:00	SW-NE	do			[2]	[2]	[2]	7	30	30,000	Everything in path destroyed.	Rosa Wallace, postmistress, Washington, Ark.
11 miles southeast of Columbus, Hempstead County, Ark.	5:00	SW-NE	½ mile			SE	All directions.	NW				Heavy hail 3 to 4 miles on west side; light hail at Columbus; barometer at Columbus fell 0.10.	R. C. Stuart, Columbus, Ark.
1½ miles east of Blevins, Hempstead County.	5:20	SW-NE	½ to 1½ miles.	Funnel shaped.	Rotary	SE	do	NW	9	34	[3] 200,000	57 residences destroyed, 75 residences damaged, 41 barns destroyed.	W. O. Beene, Blevins, Ark.
Mount Pisgah, Pike County.		S-NE	½ mile			[4]	[4]	[4]	1	24	50,000		H. W. Guise, postmaster, Delight, Ark.
Pike City, Pike County [5]													H. M. Lintz, Pike, Ark.
Gravelly, Yell County	3:30	SW-NE	125 yards			S-SW.	NE	NE	1	15	50,000		Thos. B. Frizzell, postmaster, Gravelly, Ark.
Danville, Yell County [6]													Newspaper reporter.
Chicklah Mountain, Yell County.	4:20				Straight blow.							Considerable damage.	Do.
1½ miles northwest of Appleton, Pope County.	5:00	SW-NE	200 yards			[4]	[4]	[4]	4	6			J. A. Jones.
Marche, Pulaski County.	8:18	SW-NE								5		7 homes destroyed, stock killed.	Max Malschowski.
Wrightsville, Pulaski County.	8:45	SW-NE	300 feet	Funnel shaped.	Rotary						2,500	Buildings damaged.	J. C. Cook.

[1] About.
[2] Every direction.
[3] $25,000 crops.
[4] All directions.
[5] No storm; clouds black, heavy rain; leaves, etc., scattered through vicinity.
[6] Storm passed over too high to do damage.

LOCAL STORMS IN MISSISSIPPI.

By R. T. LINDLEY, Meteorologist.

[Weather Bureau, Vicksburg, Miss., June 6, 1921.]

Violent local storms traversed portions of seven counties of Mississippi during the night of April 15–16 or on April 16. On account of the storms occurring during the night, mostly, funnel-shaped clouds, characteristic of the tornado, were not observable, although the destruction wrought, the accompanying sounds, and the directions in which débris were scattered gives basis for the belief that some, if not all, the storms may have been true tornadoes.

One, on the night of the 15th–16th, passed over a portion of the course laid waste by the tornado of March 16, 1919, from near Grace, Issaquena County, to the vicinity of Pantherburn, in Sharkey County, with heavy resultant damage, but, fortunately, without loss of human life. One person was killed and 10 were injured in portions of Noxubee and Lowndes Counties during the early morning of the 16th, and considerable damage was done, at about the same time, without loss of human life, near Hazlehurst, Copiah County. On April 16, 1 person was killed and 15 were injured by a violent local storm, characterized by observers as a tornado, in the southwestern portion of Kemper County, in the vicinity of Rio. Also, at about the same time, extensive property damage resulted, with injuries to 10 persons, from the occurrence of a local storm in the vicinity of the New Zion settlement, in the eastern portion of Amite County.

Three local storms, doing considerable damage, occurred on the afternoon of April 26. Two, affecting portions of Copiah and Lincoln Counties, were of relatively slight importance, but the third practically demolished Braxton, a town of about 300 population, in Simpson County, leaving but two buildings standing, causing the death of 15 persons and serious injuries to 23. From all accounts this storm was of true tornado type.

THE TORNADOES OF APRIL 16, 1921, IN ALABAMA.[1]

By P. H. SMYTH, Meteorologist, and J. W. SMITH, Observer.

WEATHER CONDITIONS AT 7 A. M.

A disturbance of considerable intensity centered in the middle Mississippi Valley, with a comparatively wide trough of low pressure extending southward to the Gulf of Mexico. A marked temperature gradient existed between Cairo, Ill., and Columbia, Mo., and freezing ex-

[1] Full details of these storm have been compiled and are on file at the offices of the U. S. Weather Bureau, Washington, D. C., and Montgomery, Ala.

tended as far south as the Texas Panhandle. Temperatures in Alabama ranged from 62° at Florence to 72° at Mobile. Shortly before 7 a. m. the towns of Ralph, Tuscaloosa County, and Pushmataha, were struck by tornadoes, and the northwestern counties of the State were recovering from the effects of the tornado that devastated portions of that section just after midnight. (See weather maps on p. 255.)

GENERAL SUMMARY OF THE FIVE TORNADOES.

At least five separate tornadoes are believed to have occurred in the State on the 16th, the first beginning at midnight and the last ending about 2.15 p. m. These tornadoes, together with the severe local thundersqualls and torrential rains that accompanied them and occurred elsewhere in the State, did enormous damage. Definite estimates are difficult to make, but it is known that not less than 13 persons were killed, more than 50 injured, and not less than $1,000,000 damage was done. Most of this damage was the result of the tornadoes, and was restricted to limited stretches in their paths, but the damage over wide areas to fences, trees, outbuildings, etc., by the thundersqualls, to roads, streets, plowed fields, etc., by the washing rains; and to culverts, bridges, crops, etc., by the freshets that followed is known to have been considerable. It is thought that complete information would materially add to the estimate of damage given.

Many interesting facts are brought out by the accompanying map (fig. 1) which shows the times of beginning and ending of rainfall and the location of the paths of the tornadoes. The tornadoes are seen to skirt the southeastern edge of the rain area in every case except the Gallion storm, which was the most local of the five. This strengthens the statements usually made that heavy rainfall does not precede tornadoes. A marked southeastward extension of the rain area is noted between 6 a. m. and 8 a. m., and 12 noon and 2 p. m.; during these four hours two of the tornadoes were in progress. There is a noticeable change in the direction of the tracks toward the east as the day advanced and the LOW moved northeastward. It is noted that tornado tracks, in recent years at least, seem to show a more easterly direction in southeastern Alabama than in the northwestern part of the State.

A chart of all available wind directions reported by cooperative observers (fig. 2) shows that no important variations in wind direction obtained at 7 a. m., the winds being generally south or southeast. At Montgomery there was no permanent shift of the wind to the northwest until the morning of the 17th, although there was the usual temporary shift accompanying the thundersquall. Stratus clouds at Montgomery were from the southwest throughout the 16th, and it would seem likely that there was an overflow of the wind-shift line of the LOW to the southeastward at a moderate elevation. It is not believed that the wind-shift line at the surface reached Alabama.

The distribution of rainfall over Alabama is shown by figure 3. An attempt has been made to adjust the data to a midnight-to-midnight total, the time of beginning and ending of precipitation being utilized to accomplish this as far as possible. Six areas of 4 inches or more of precipitation are shown. In most cases these lie to the southeast of one of the tracks of the tornadoes. The last tornado traversed a section where less than 2 inches of rain fell, although rainfall in the immediate track of this storm was reported very heavy, being estimated at between 3 and 4 inches in the section northwest of Wetumpka.

An interesting feature connected with the tracks of the first and last of the tornadoes is that they follow the same general tracks as the Marion County tornado of April 20, 1920, and the Deatsville-Agricola and West Point tornado of March 28, 1920. (See fig. 4.)

TORNADOES IN TENNESSEE ON APRIL 16, 1921.

By R. M. Williamson, Meteorologist.

[U. S. Weather Bureau, Nashville, Tenn., May 27, 1921.]

A depression over the central Mississippi Valley was attended by heavy rainfall with much thunder and lightning and severe local storms in Tennessee during the night of the 15–16th. (See weather maps, figs. 1 and 2, p. 255.) The greatest damage resulted in the south-central counties, where several tornadoes occurred about 4 a. m.

One was first observed 5 miles southwest of Lynnville, Giles County, from which place it moved northeastward to Gileston, 1 mile south of Lynnville, and thence into Marshall County, spending its force, apparently, near Mooresville, a few miles northeast of Lynnville. At Gileston 36 empty freight cars were more or less wrecked, entailing a loss of about $10,000. Just east of Lynnville several dwellings and many outhouses were blown down, a child was killed, and a number of persons were injured. Along other parts of its course of 12 miles or more there was much damage to houses, trees, fences, etc. The total damage from this storm was about $35,000.

Another tornado passed through Cornersville, in the southern part of Marshall County, about 4 a. m., destroying much property and injuring twelve or fifteen persons, one of whom died several days later. The loss in this vicinity was said to be about $30,000. The storm next appeared near Palmetto, Bedford County, where barns, trees, and fences were blown down but no serious damage occurred. There were sections along its course several miles in length where the storm evidently lifted, as the destruction was slight. It is very probable that this storm continued northeastward into Rutherford County, becoming active again in the vicinity of Dennis and Readyville, where many houses were partially wrecked about 5 a. m. If this be true, the distance covered during the hour was about 45 or 50 miles. The total loss was probably not less than $50,000.

The observer at Coldwater, in the southwestern part of Lincoln County, reports considerable property destroyed and several persons seriously injured in a tornado that passed 2 miles north of that station.

About 9 a. m. of the same date, the town of Newport, Cocke County, in the eastern part of the State, was struck by a tornado, moving from west to east and cutting a path 50 feet wide along Main Street. Damage to shade trees, houses, automobiles, wires, etc., amounted to five or six thousand dollars. The comparatively small damage was due to the fact that the storm's path was narrow and, apparently, did not reach the residences and other buildings. Few persons were out of doors, due to a heavy rain falling, and only three were injured. After traversing four city blocks the storm lifted and struck again in the timber east of the town.

Tornadoes occur much less frequently in east Tennessee than in the western half of the State. It is interesting to note in this connection that two previous storms of this character occurred in the vicinity of Newport, according

P. H. S. & J. W. S. Chart I. Location of tracks of tornados in Alabama, April 16, 1921.

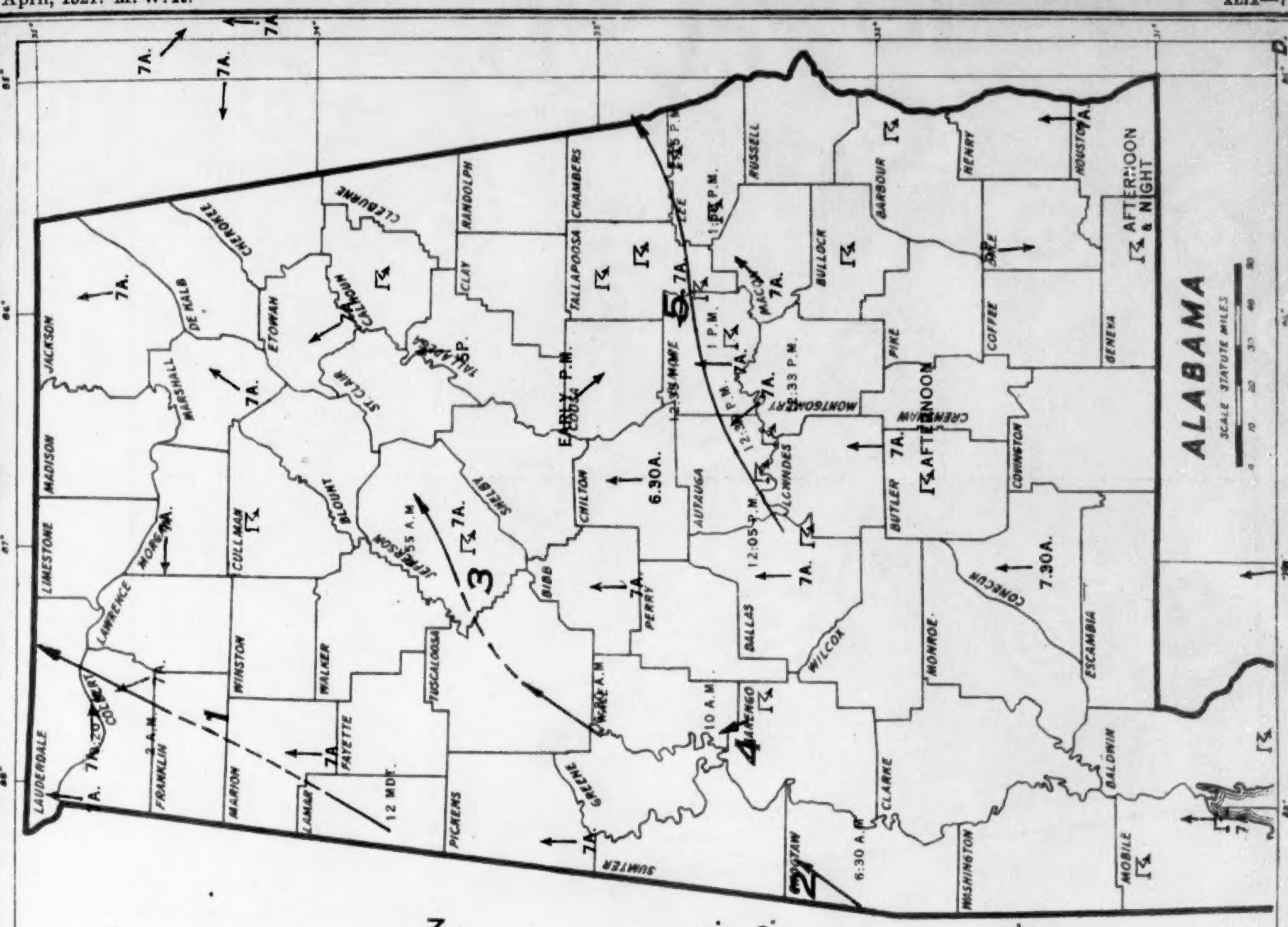


FIG. 2.—Tornado tracks and time of occurrence in red. Thunderstorms reported, wind direction, and time in black.

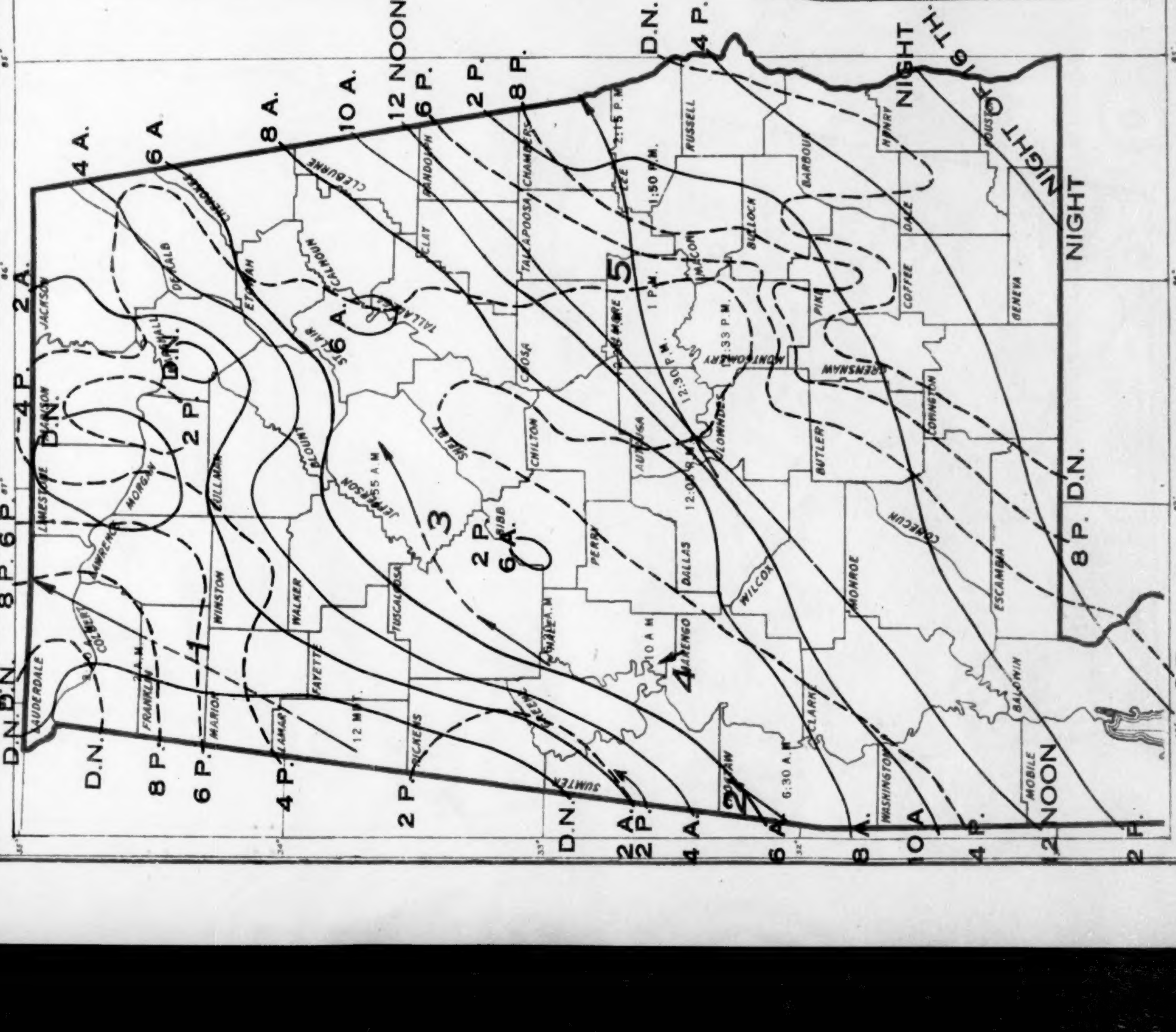


FIG. 1.—Tornado tracks and time of occurrence in red. Times of beginning and ending of rain in black; solid for beginning, dashed for ending. The tracks are numbered in red in the order of their occurrence.

P. H. S. & J. W. S. Chart II. Location of tracks of tornados in Alabama, April 16, 1921.

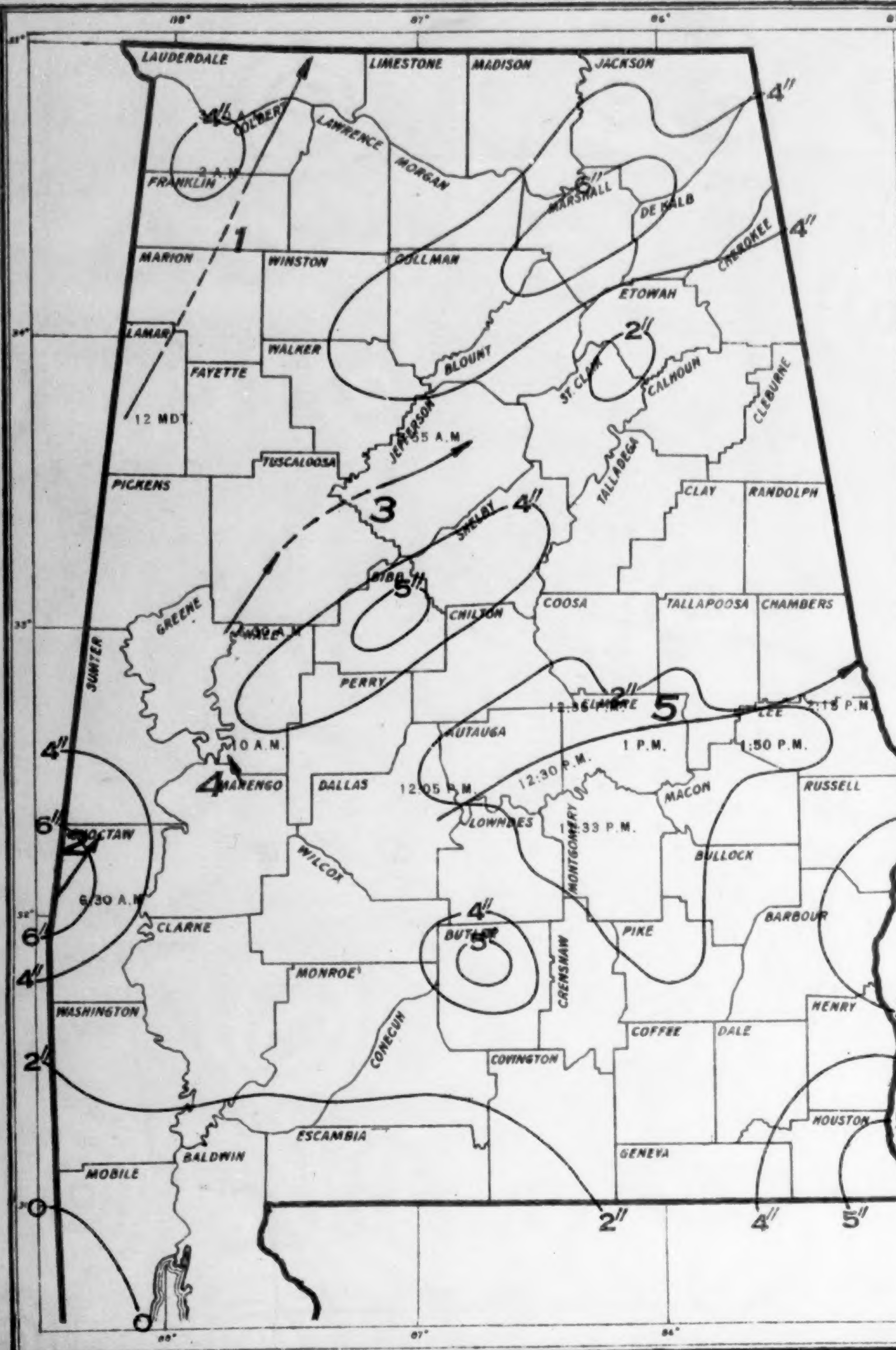


Fig. 3.—Distribution of precipitation, April 16, 1921.

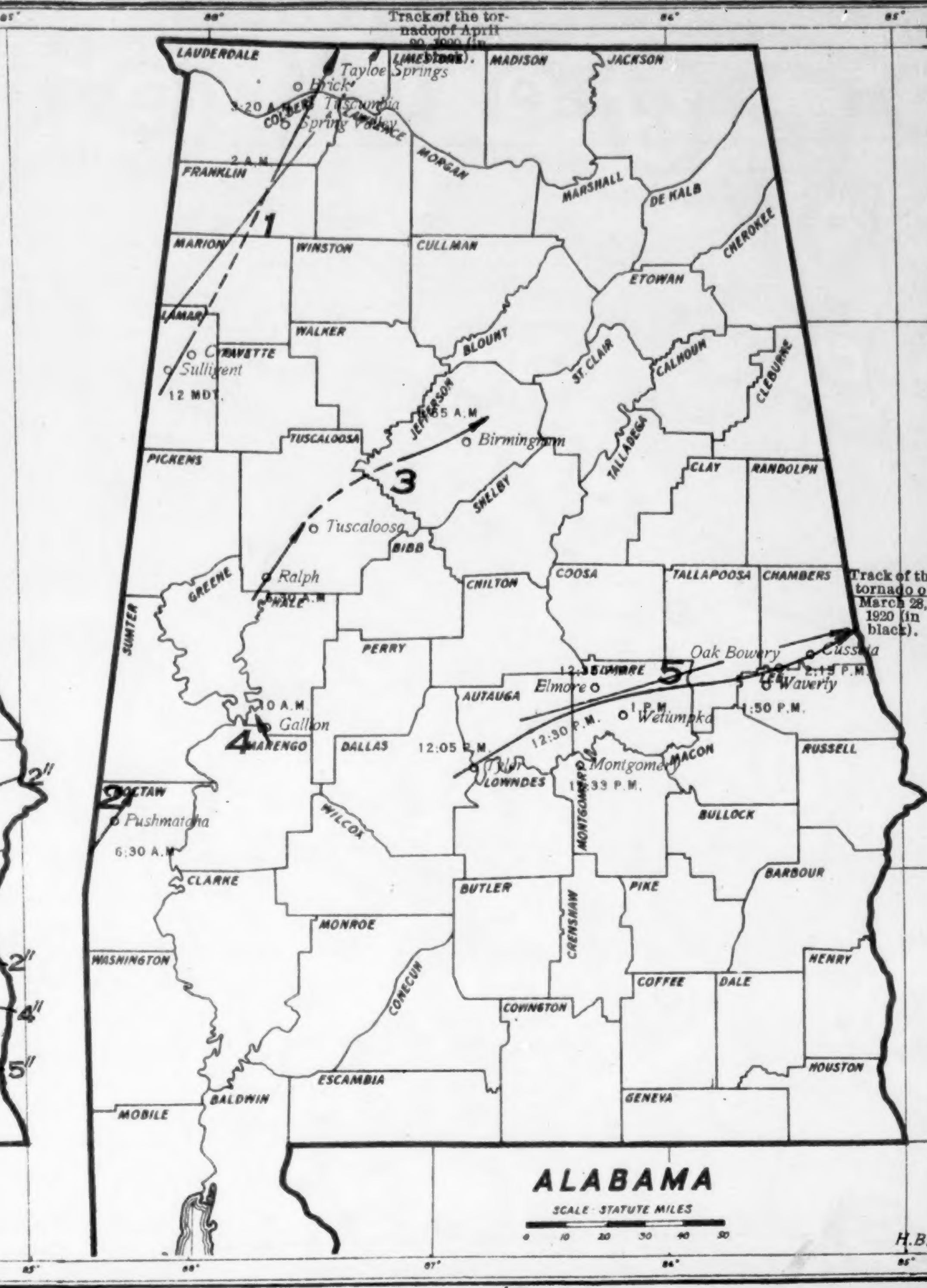


Fig. 4.

to the cooperative observer. One was in April, 1884, when several buildings were totally wrecked, and the other on June 15, 1896.

Accompanying the tornadoes mentioned in the first several paragraphs the rainfall was quite heavy in some of the central counties, reaching nearly five inches at a few points. Streams were very high, low lands were flooded, and much damage was done to crops by washing. During the same night lightning caused the destruction of barns in several counties, particularly at Cookeville, Putnam County, Loretto, Lawrence County, and Savannah, Hardin County.

The approximate paths of the tornadoes are indicated on the weather map, figure 2, page 255.

CYCLONIC STORM OF JULY 1, 1920, AND ITS EFFECT ON POND ELEVATION AT THE DAM OF THE MISSISSIPPI POWER CO., AT KEOKUK, IOWA.

By R. H. BOLSTER.

[Hydraulic Department, Mississippi River Power Co., Keokuk, Iowa, Sept. 16, 1920.]

On the evening of July 1 Keokuk, Iowa, was visited by probably the worst wind storm in its history. Practically without warning the wind velocity increased from 5 miles per hour at 9:12 p. m. to a velocity of approximately 125 miles per hour at 9:20 or eight minutes later. For three successive periods of about two minutes each, and at striking in the vicinity of Montrose. It then followed down the river with its maximum intensity apparently at Keokuk. No traces of its effect were noticeable south of tower No. 12 on the transmission line, or 10 miles south of Hamilton, which is in direct line with the river from Montrose to Keokuk. No severe wind

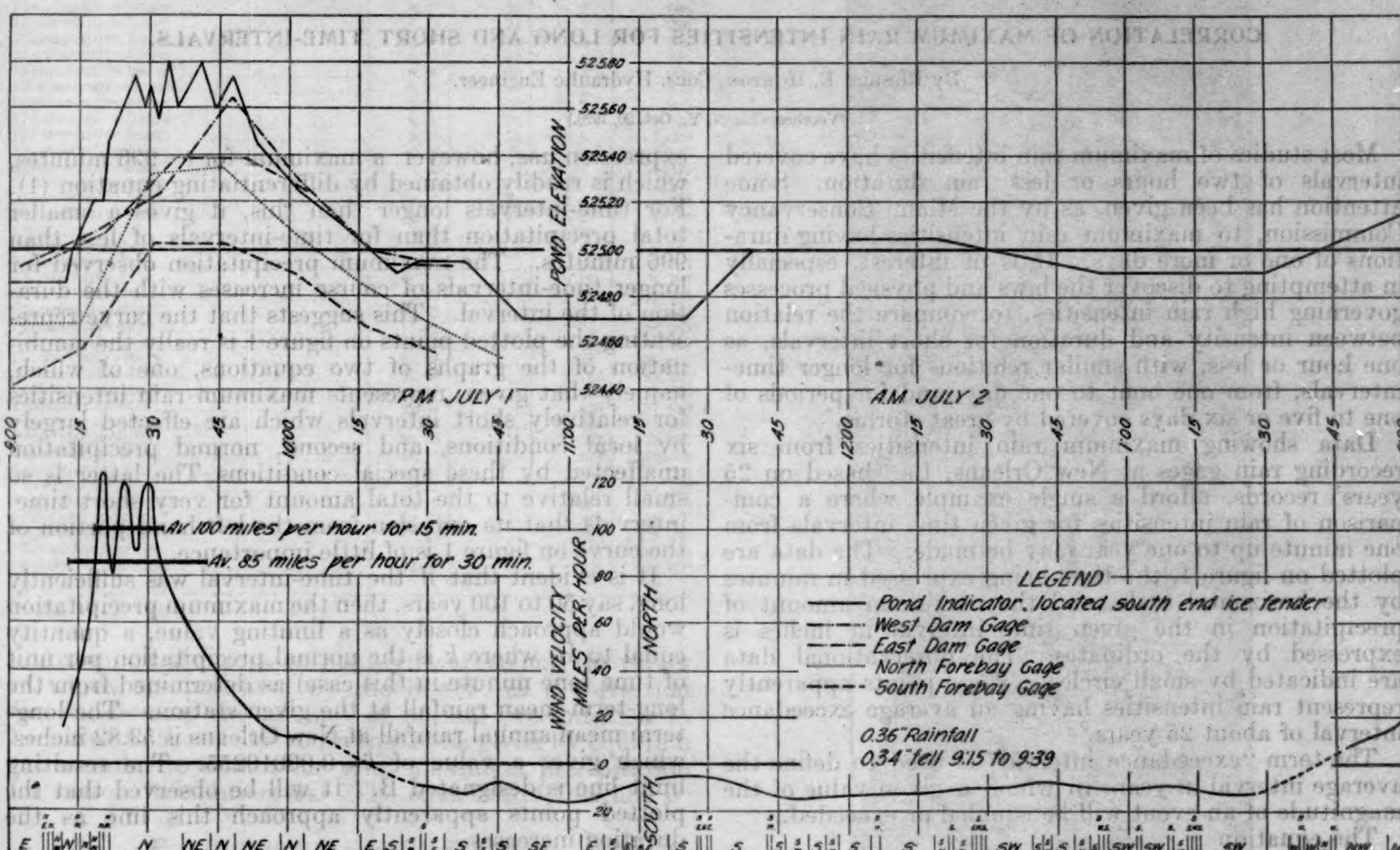


FIG. 1.

intervals of about five minutes, the wind velocity averaged 110 miles per hour, and a few seconds in each period the average was approximately 120 miles per hour. Over a period of 15 minutes the average velocity was 100 miles per hour and over a period of 30 minutes the average velocity was 85 miles per hour. At 9:55 o'clock the velocity had fallen to 18 miles per hour and at 10 o'clock it was 11 miles per hour. A total of 0.36 inch of rain fell, 0.34 inch being concentrated between 9:15 and 9:39 p. m. (See fig. 1.)

The storm was confined to a very small area. The wind which was generally easterly in direction before the storm, backed around into the north and northwest, occurred at Fort Madison or outside of a few miles east and west of the main path of the storm. The local Weather Bureau official states that the storm was of the ordinary cyclonic type although its apparent drop from a high altitude to earth and back again was a characteristic of the tornado. Some have claimed that a funnel-shaped cloud accompanied the storm but this is very doubtful.

The Mississippi River Power Co. sustained no damages from the storm, but in the city of Keokuk a great deal of damage was done to trees and wires. Many streets were rendered impassable and trees up to 3 feet in diameter were blown over.

It would have been of interest to compare the wind velocity of this storm with that of the historic storms at Galveston and Houston. Mr. Daly states that at both of these places the anemometer blew off at 125 miles per hour. The anemometer of the power company is located at the top of the 60-foot flagstaff at the north end of the building and is 162 feet above the elevation of the lake or at elevation 687 feet M. D.

The effect of the wind on the various plant gages is not easy to understand. All of the plant gages are dampened down so that some have an opening from the gage well to the pond no larger than a lead pencil. This partly but not wholly explains the lag in effect on the gages after the wind began to blow. Note how closely the east and west dam gages follow the indicator on the falling side. It seems reasonable to believe that such a short sharp blow as occurred would not have been very uniformly distributed as to intensity over the area which it covered. Furthermore there would be a tendency toward higher water elevations in contracted places like the location of the ice fender indicator. Note also that all the gages, with the exception of the indicator, record only at 15-minute intervals and hence do not register changes in pond level as completely as the indicator. The change in pond elevation (rise) was 0.95 foot by the indicator and 0.72 foot by the east dam gage. If the high wind had continued longer both the east and west dam gages would probably have registered as high elevations as the indicator.

A series of surges occurred in the pond following the storm as shown by the indicator curve. These surges from crest to trough were of about one and one-fourth hours' interval. This would indicate that the surges went no farther upstream than Montrose, where the storm originated, for the time interval of wave movement between Fort Madison and the dam is two and one-half hours. The wave crest shown on the chart at 2 a. m. is the last one before the pond settled down to a constant elevation.

CORRELATION OF MAXIMUM RAIN INTENSITIES FOR LONG AND SHORT TIME-INTERVALS.

By ROBERT E. HORTON, Cons. Hydraulic Engineer.

[Voorheesville, N. Y., Oct. 20, 1920.]

Most studies of maximum rain intensities have covered intervals of two hours or less rain duration. Some attention has been given, as by the Miami Conservancy Commission, to maximum rain intensities having durations of one or more days. It is of interest, especially in attempting to discover the laws and physical processes governing high rain intensities, to compare the relation between intensity and duration for short intervals, as one hour or less, with similar relations for longer time-intervals, from one hour to one day, and for periods of one to five or six days covered by great storms.

Data showing maximum rain intensities from six recording rain gages at New Orleans, La., based on 25 years' records, afford a single example where a comparison of rain intensities for given time intervals from one minute up to one year may be made. The data are plotted on figure 1, the time being expressed in minutes by the horizontal scale, and the maximum amount of precipitation in the given time interval in inches is expressed by the ordinates. The observational data are indicated by small circles. These points apparently represent rain intensities having an average exceedance interval of about 25 years.

The term "exceedance interval" is used to define the average interval in years in which a given value of the magnitude of an event will be equaled or exceeded.

The equation

$$P_e = \frac{44tE - t^{0.222}}{60} \quad \cdots\cdots\cdots \quad (1)$$

was worked out, using coefficients determined from the observational data for short durations. The values given by this equation are indicated on the diagram by triangles.

It will be seen that this simple expression represents with remarkable fidelity the observational data for time-intervals of 480 minutes, or eight hours, or less. This expression has, however, a maximum for $t = 996$ minutes, which is readily obtained by differentiating equation (1). For time-intervals longer than this, it gives a smaller total precipitation than for time-intervals of less than 996 minutes. The maximum precipitation observed for longer time-intervals of course increases with the duration of the interval. This suggests that the curve representing the plotted points on figure 1 is really the combination of the graphs of two equations, one of which, namely that given, represents maximum rain intensities for relatively short intervals which are effected largely by local conditions, and second, normal precipitation unaffected by these special conditions. The latter is so small relative to the total amount for very short time-intervals that its omission from the left-hand portion of the curve on figure 1 is of little importance.

It is evident that if the time-interval was sufficiently long, say 50 to 100 years, then the maximum precipitation would approach closely as a limiting value, a quantity equal to kt, where k is the normal precipitation per unit of time (one minute in this case) as determined from the long-term mean rainfall at the given station. The long-term mean annual rainfall at New Orleans is 53.82 inches, which gives a value of $k = 0.00010255$. The resulting limit line is designated B. It will be observed that the plotted points apparently approach this line as the duration increases.

The line C shows a continuation of the exponential function (1) beyond its maximum point. The value of this function becomes negligible for time-intervals exceeding 500,000 minutes. The portion of the curve DE represents the sum of the values of the curve C plus the values of some function which approaches the limit line B as the time-interval increases. Actually, the nature of this function is unknown, but it is probably some form of exhaustion equation, or exponential function, as is also the expression already given for the rainfall amount for time-intervals of one day or less.

Relative maximum rain intensities for various time-intervals from records of six recording rain gages at New Orleans, La., 1894 to 1918, inclusive.

[Geo. G. Earl, Mun. and County Eng. April, 1919, p. 122.]

Time-interval.	Maximum. Amount intensities.	Intensities per hour.	Intensities per 24 hours.	Minutes.
(1)	(2)	(3)	(4)	(5)
3 consecutive minutes	0.63	12.60	302.4	3
5 consecutive minutes	.84	10.08	241.9	5
15 consecutive minutes	1.73	6.92	166.1	15
30 consecutive minutes	2.64	5.28	126.7	30
45 consecutive minutes	2.99	3.99	95.8	45
1 hour	3.53	3.53	84.7	60
2 consecutive hours	4.66	2.33	55.9	120
3 consecutive hours	5.80	1.93	46.3	180
4 consecutive hours	6.60	1.65	39.6	240
5 consecutive hours	7.02	1.40	33.6	300
6 consecutive hours	7.10	1.18	28.3	360
7 consecutive hours	7.30	1.04	25.0	420
8 consecutive hours	7.40	.93	22.3	480
9 consecutive hours	7.50	.83	19.9	540
10 consecutive hours	7.60	.76	18.2	600
11 consecutive hours	8.37	.76	18.2	660
12 consecutive hours	8.75	.73	17.5	720
13 consecutive hours	8.81	.68	16.3	780
14 consecutive hours	8.81	.63	15.1	840
15 consecutive hours	9.06	.60	14.4	900
15½ consecutive hours	9.21	.59	14.2	930
16 consecutive hours	9.21	.58	13.9	960
17 consecutive hours	9.30	.55	13.2	1,022
18 consecutive hours	9.35	.52	12.5	1,080
19 consecutive hours	9.40	.49	11.8	1,140
20 consecutive hours	9.50	.47	11.3	1,200
21 consecutive hours	9.60	.46	11.0	1,260
22 consecutive hours	9.70	.44	10.6	1,320
23 consecutive hours	9.75	.42	10.1	1,380
1 day	9.80	....	9.80	1,440
2 consecutive days	9.90	....	4.95	2,880
3 consecutive days	9.90	....	3.30	4,320
4 consecutive days	11.51	....	2.88	5,760
5 consecutive days	12.73	....	2.55	7,200
6 consecutive days	12.82	....	2.13	8,640
7 consecutive days	14.01	....	2.00	10,080
8 consecutive days	14.12	....	1.76	11,520
15 consecutive days	22.24	....	1.48	21,600
30 consecutive days	23.00	....	.767	43,200
1 calendar month [1]	16.01	....	.533	43,920
2 calendar months	26.62	....	.436	87,840
3 calendar months	30.81	....	.335	131,760
4 calendar months	36.48	....	.297	175,600
5 calendar months	41.75	....	.273	219,500
6 calendar months	47.69	....	.255	263,400
7 calendar months	51.58	....	.243	307,300
8 calendar months	55.19	....	.227	351,200
9 calendar months	59.87	....	.219	395,100
10 calendar months	67.73	....	.223	439,200
11 calendar months	71.74	....	.214	482,900
12 calendar months	74.68	....	.204	526,800

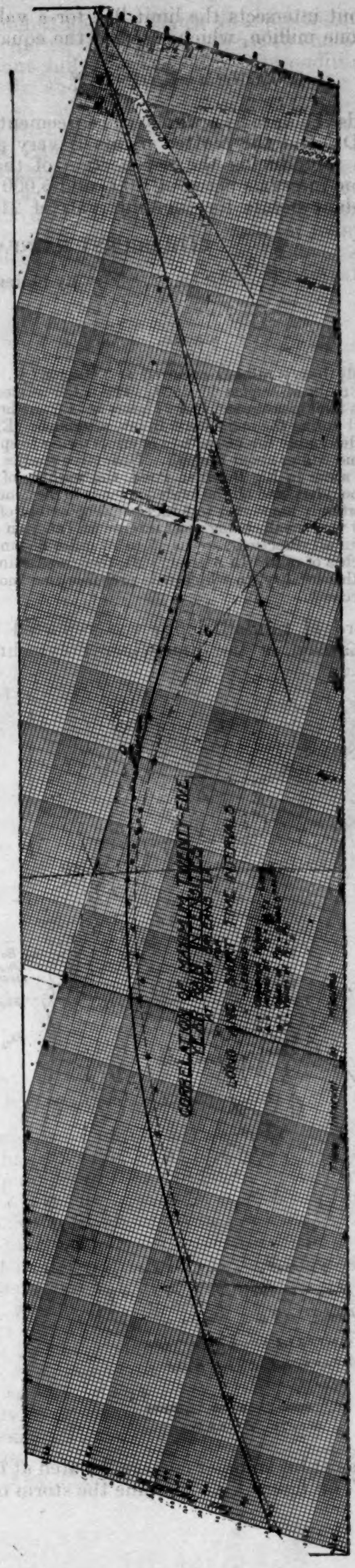
[1] Taken as 30.5 days.

An empirical expression has been worked out, the values of which are indicated by the line F, as a correction factor, showing the amount of normal precipitation to be added to the excessive precipitation given by equation (1) in order to obtain the total maximum precipitation for various time-intervals. The equation of this line is:

$$P_n = 0.0166t^{0.635} \text{ and } P = P_e + P_n. \quad (2)$$

Combining the results of equations (1) and (2), and plotting the corresponding values of P, results indicated by the line ADE are obtained. It will be noted that this line gives slightly higher values of the precipitation amounts for short time intervals than does equation (1) alone, however the data for a given number of consecutive hours, days, or months, probably does not represent quite the true maximum amount of precipitation for an equivalent number of consecutive minutes, the difference being larger for short than for longer time-intervals, so that the left-hand portion of the curve ADE possibly represents more nearly the true values which would be determined from homogeneous time intervals than do the data themselves.

The equation for P_n here used is of course not rational, since its curve does not approach the limit line B as t



increases, but intersects the limit line for a value of t a little over one million, which satisfied the equation

$$0.0001025t = 0.0166t^{0.635}$$

As regards the data as a whole, the agreement between the line ADE and the plotted points is very good, the curve even reproducing the flat portion of the plotted data for time-intervals between 1,000 and 5,000 minutes. The discordant points for time-intervals of 21,000 and 43,000 minutes, respectively, are probably due to rain intensities for these time-intervals having occurred "out of their order," or with greater frequency during the 25 years of observations than would be the case on the average. It appears that the equation for the line ADE given on the diagram represents with considerable accuracy the maximum amounts of precipitation having average exceedance intervals of about 25 years at New Orleans for time-intervals ranging all the way from 1 minute to 1 year.

CLOUDBURST RAINFALL AT TABORTON, N. Y., AUGUST 10, 1920.

By ROBERT E. HORTON and GEORGE T. TODD.

[Albany, N. Y., Oct. 15, 1920.]

SYNOPSIS.

An extremely heavy rainfall occurred at Taborton, N. Y., on the afternoon and night of August 10, 1920. The catch as measured in a bucket, gave a total measurement for 24 hours as 11.62 inches, of which 8.95 inches fell during the main storm in late afternoon. Experiments were tried to determine the magnitude of errors owing to splash from a near-by roof and eddies about the pail. Deductive studies were made on the rise of water in Big Bowman Pond, the washing of roads, and dislodging of boulders, and all the evidence tends to the conclusion that the rainfall certainly amounted to 8 inches. The extent of the heavy downpour was very small, being most intense at Taborton and falling off markedly in all directions, towns 15 to 20 miles distant receiving only 1 or 2 inches of rain. In August, 1891, there was a similar heavy downpour in this locality, in which it is probable that more rain fell than on this occasion.

The record of rainfall depth was reported by Prof. Thos. R. Lawson, of the Rensselaer Polytechnic Institute, who was at his summer cottage, located at the point marked "A" on figure 1, at the time the storm occurred.

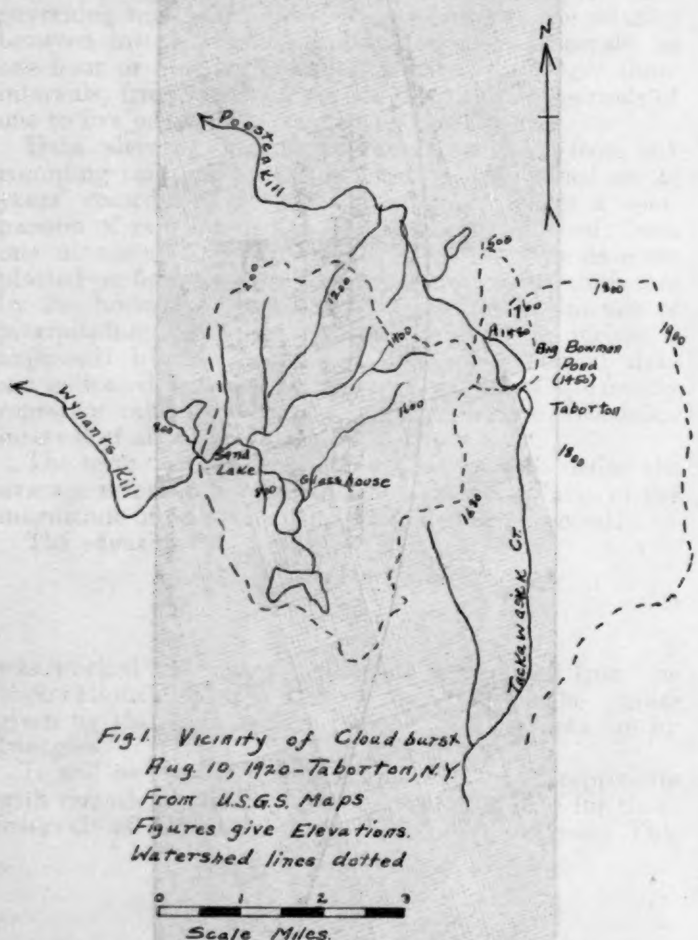


Fig. 1. Vicinity of Cloudburst Aug. 10, 1920 - Taborton, N.Y. From U.S.G.S. Maps Figures give Elevations. Watershed lines dotted

There was an ordinary tin pail with flaring sides standing on the ground 8 feet from the south corner of the house, as shown in figure 2. Where the pail stood the grass was short and the ground hard, and the pail stood level.

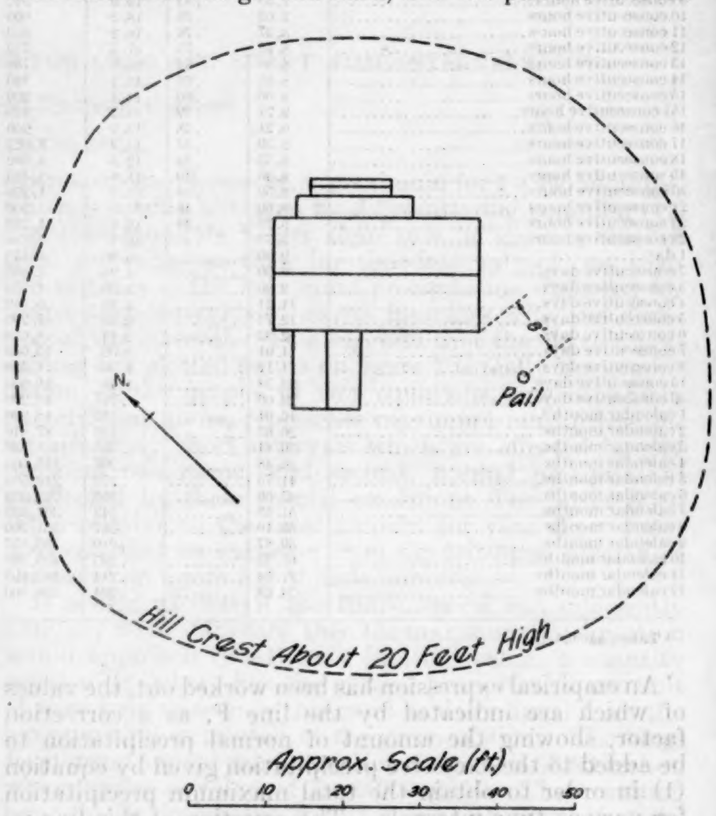


FIG. 2.—Details of location of pail near house.

The mean top diameter inside was 10 inches—mean bottom diameter 7¼ inches—and depth 8⅜ inches. Prof. Lawson reports that the pail was empty before the rain. The rain began about 4 p. m., fast ["summer"] time, and the heaviest storm ended about 6 p. m. There was a lull between 5 and 6 p. m., at which time he found the pail full. He then emptied and replaced it, and at the end of the rain it was again half full or nearly so.

The surface area, or catchment of the pail, is 78.54 square inches. The pail being a truncated cone, the true depth of rainfall caught has been obtained by determining the height of a cylinder of equal volume and having a diameter of 10 inches. This amounts to 6.28 inches. The volume in the bottom half of the pail caught after the lull, reduced to the same basis is equivalent to a cylinder 10 inches in diameter and 2.67 inches high, making the total rainfall caught in the main storm equivalent to 8.95 inches.

In the second storm, about midnight, the same day, nearly one-half a pailful, or around 2.67 inches, was caught, making the total depth by pail measurement for 24 hours 11.62 inches.

The only question which can be raised regarding these measurements is whether they were affected by wind or by wash from the eaves of the house, which was without eave troughs. Prof. Lawson reports that there was very little wind. It seems impossible to the writer [R. E. H.] that so heavy a rainfall could occur locally without wind, as the apparent precipitation by the pail measurement several times exceeds the total or normal moisture content of the atmosphere; however, it might be possible that the air was quiet near the ground and that the ascending moist air currents which produced the rain slid up the slopes of a virtual air mountain. It would take but little wind with the rain gage located as was the pail in this instance to produce eddies likely to affect seriously the catch of rainfall.

The roof of the house is steep, well shingled, and relatively smooth. In order to determine how far rain swashing off from such a roof would be projected before reaching the ground I performed an experiment by pouring water near the ridge of a similar roof so that it flowed off in a sheet, such as is not infrequently observed in swashing storms. I found that the largest drops struck the ground at distances 4 to 5 feet from the building, and produced some splash and mist from rebound at even greater distances. The washing of roads and flooding of fields in the vicinity affords abundant evidence that this was an extraordinary rainfall. A rough check on the amount of precipitation is afforded by Prof. Lawson's own observations of the rise in Big Bowman Pond (see fig. 1). Prof. Lawson stated that on August 18, at the time of my visit, this pond was 1 foot higher than it was before the rain of August 10. The high-water mark of the morning of August 11, as pointed out by Prof. Lawson, was about 14 inches above the stage of the lake August 18; however, it was Prof. Lawson's opinion that the lake rose a total of about $2\frac{1}{2}$ feet in the night of August 10 and 11.

The water surface area of the lake is 0.15 square mile, or 4,180,000 square feet. It has a drainage area, as shown on the topographic map, of 0.95 square mile, or, in other words, the land surface is 0.80 square mile, or 5.3 times the water surface. The outflow rate August 10 was 2 or 3 cubic feet per second. With the lake raised 1.5 feet higher, the outflow rate might be 10 to 15 cubic feet per second. The excess outflow during the night of August 10, in excess of the amount which would have occurred at the initial stage of the lake, would amount to about 10 cubic feet per second for 12 hours, or roundly 0.1 foot or $1\frac{1}{4}$ inches, so that the rainfall on the lake surface plus inflow to the lake must be equivalent to a total of 27 to 31 inches.

The ground was previously moist, the slopes are steep, averaging about 350 feet per mile. The area is forested, and the rock very close to the surface. The rain occurred at night, and under these conditions the interception loss would be a minimum, as the evaporation rate was low and rainfall rate intense. While it is an ususually high rate of run-off for a wooded area in the summer time, yet it seems certain that under these conditions not more than 3 or 5 inches of precipitation at the most could have been lost by interception or absorbed by the shallow soil. Using 4 inches as the total loss in detention, these considerations lead to the equation:

$$P + 5.33\ (P - 4) = 30 \text{ inches}$$

from which it appears that a total precipitation of about 8 inches during the night of August 10 and 11 is sufficient to account fully for the observed conditions. Of this apparently about 78 per cent fell in the first storm, making an indicated rainfall of 6.24 in two hours. It is possible that the rain was not as heavy over the whole area as at Lawson's.

The drainage basin of Wynantkill lies immediately west of that of Big Bowman Pond, as shown in figure 1. Roads in this basin were washed out, the entire soil cover being removed down to the rocks in many places. A small dam was destroyed, and flats were generally flooded. The rainfall was very intense at Sand Lake

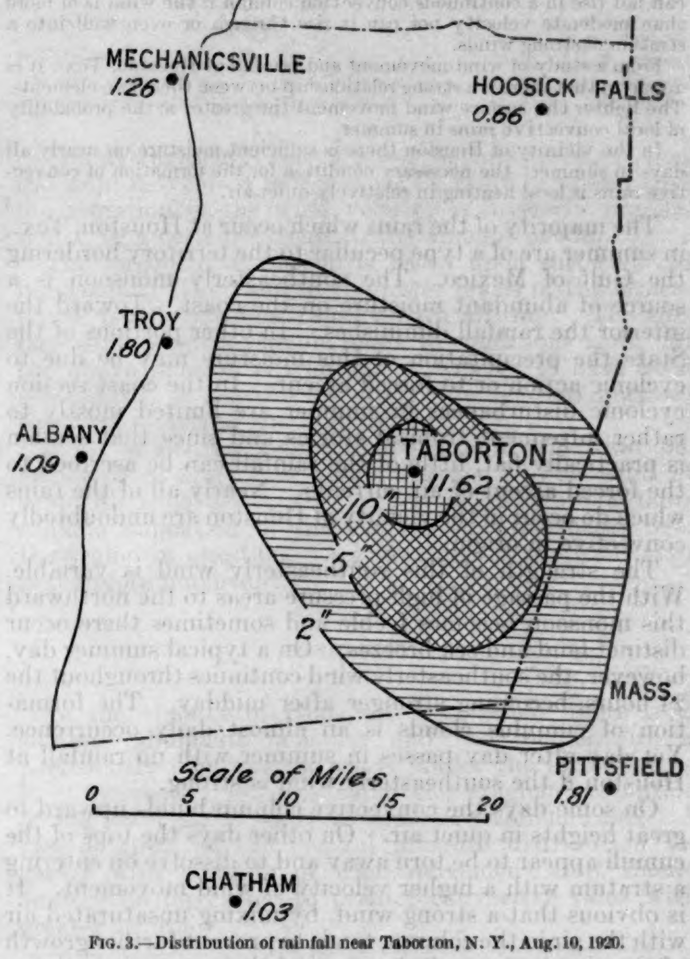


FIG. 3.—Distribution of rainfall near Taborton, N. Y., Aug. 10, 1920.

village. The dam of Charles A. Brookner's mill at Sand Lake has a level crest 65 feet long. The water rose to a maximum depth about midnight on the evening of August 10 of $33\frac{1}{2}$ inches above the crest of this dam. The dam has a flat crest about 16 inches wide, with an upstream slope of about one on three, to which a discharge coefficient in the weir formula of 3.50 would apply. During the storm two water wheels having capacities of about 40 c. f. s. were blocked open in the mill. The calculated discharge over the dam is 1,066 c. f. s., and with the water-wheel discharge added the maximum rate of discharge at this location was 1,106 c. f. s. The contributary drainage area is 10.7 square miles. The easterly two-thirds is mostly wooded, and the slopes average about 400 feet per mile. The above figures indicate a maximum run-off rate of 103.3 cubic feet per second per square mile. This is by no means an unusual maximum run-off rate for

such a drainage area. It amounts to a run-off depth of only 0.16 inch per hour. There are, however, two lakes in this basin, and the amount of stream channel storage is relatively large, so that from the same rainfall a run-off rate much larger would naturally be expected from the land area tributary to Bowman Pond.

Observers both at Sand Lake and Taborton state that 29 years ago, in August, roads were washed out and streams were slightly higher than on the recent occasion. Probably the intense rainfall of August 10 covered only the higher easterly portions of the Sand Lake Drainage Basin. (See fig. 3.)

CORRELATION OF WIND VELOCITY AND CONVECTIVE RAINS AT HOUSTON, TEX.

By I. R. Tannehill, Observer.

[Weather Bureau, Houston, Tex., Apr. 16, 1921.]

SYNOPSIS

In the vicinity of Houston, Tex., convective rains are frequent during the summer months. These rains result from expansion and consequent cooling of air rising in a nearly vertical column. The air can not rise in a continuous convection column if the wind is of more than moderate velocity nor can it rise through or even well into a stratum of strong winds.

From a study of wind movement and rainfall at Houston, Tex., it is apparent that there is a strong relationship between these two elements. The lighter the surface wind movement the greater is the probability of local convective rains in summer.

In the vicinity of Houston there is sufficient moisture on nearly all days in summer; the necessary condition for the formation of convective rains is local heating in relatively quiet air.

The majority of the rains which occur at Houston, Tex., in summer are of a type peculiar to the territory bordering the Gulf of Mexico. The southeasterly monsoon is a source of abundant moisture on the coast. Toward the interior the rainfall diminishes. In other portions of the State the precipitation of this moisture may be due to cyclonic action or to forced ascent. In the coast section cyclonic disturbances in summer are limited mostly to rather infrequent tropical storms and since that section is practically flat, little of the rainfall can be ascribed to the forced ascent of air currents. Nearly all of the rains which do occur in the vicinity of Houston are undoubtedly convective in origin.

The strength of this southeasterly wind is variable. With the passage of high-pressure areas to the northward this monsoon becomes feeble and sometimes there occur distinct land and sea breezes. On a typical summer day, however, the southeasterly wind continues throughout the 24 hours, becoming stronger after midday. The formation of cumulus clouds is an almost daily occurrence. Yet day after day passes in summer with no rainfall at Houston if the southeasterly wind is strong.

On some days the convective column builds upward to great heights in quiet air. On other days the tops of the cumuli appear to be torn away and to dissolve on entering a stratum with a higher velocity of wind movement. It is obvious that a strong wind, by mixing unsaturated air with the air in the column, tends to prevent further growth of the cloud mass. Quiescence of the upper air is therefore an aid if it is not on some occasions essential to the formation of convectional columns to great altitudes.

Similarly, quiescence of the surface air favors the starting of convections, since it permits, as strong winds do not, appreciable local inequalities of temperature.

From observation it therefore appears that the prevailing southeasterly wind at Houston is productive of abundant rainfall when conditions are favorable for convection and that the important consideration is the strength of this southeasterly current.

Concerning convective rains, Prof. A. J. Henry, in Weather Forecasting in the United States, says:

> There are two districts in which convective rains occur during the warm season. The first of the districts is along the Gulf coast, including the Florida peninsula, and extending back into the interior probably not more than 50 miles, the exact border not being as yet determined. Its east-west length is approximately 700 miles, or from the Atlantic in the neighborhood of Jacksonville, Fla., to about Houston, Tex. The pressure conditions associated with these rains are about as follows:
>
> A high, with pressure 30.15 to 30.20 inches, overlies the southern portion of the middle Atlantic, with an extension over the Florida peninsula, in which the pressure is 30.08 to 30.10 inches. Pressure diminishes in a westerly direction to a region of indifferent gradients over southeastern Louisiana. The gradients are for gentle southeast winds along the coast and over the narrow fringe of the interior.

In the foregoing quotation it is pointed out that the pressure distribution is such as to give rise to gentle southeast winds.

The temperature of the air does not differ materially from one summer day to another in this section. On nearly all days there is an abundance of moisture. The important consideration seems to be the velocity of the southeast wind. When the wind is strong, rain is prevented by mixing, and the moisture is carried farther into the interior.

The records at Houston, Tex., covering a period of 11 years, 1910 to 1920, inclusive, were examined in an effort to determine any relationship that exists between rainfall and wind. During this period the anemometer and the rain gage have not been moved.

Table 1.—*Average wind velocity, miles per hour, and the number of rainy days, 0.01 inch or more, for each of the months June, July, and August.*

Year.	June.		July.		August.	
	Average wind movement (miles per hour).	Number of days with 0.01, or more, rainfall.	Average wind movement (miles per hour).	Number of days with 0.01, or more, rainfall.	Average wind movement (miles per hour).	Number of days with 0.01, or more, rainfall.
1910	7.4	9	7.4	11	7.1	6
1911	7.1	9	6.7	13	6.8	9
1912	8.5	9	6.3	12	6.9	11
1913	8.1	9	7.5	5	6.3	10
1914	6.7	7	6.7	5	6.7	18
1915	8.2	2	7.9	5	8.3	17
1916	8.3	7	5.9	13	6.6	14
1917	8.7	3	7.6	7	6.8	4
1918	6.9	5	6.7	6	6.6	9
1919	7.4	13	5.0	12	5.8	11
1920	6.7	10	6.1	12	5.5	17

For the values in Table 1, the coefficient of correlation [1] has been computed by the method of least squares. The equation used was

$$r = \frac{\Sigma\,(xy)}{\sqrt{\Sigma x^2 \Sigma y^2}}$$

for the correlation coefficient and

$$E_r = 0.674\,\frac{1-r^2}{\sqrt{n}}$$

[1] See: The Effect of Weather upon the Yield of Corn, Mo. Weather Rev., Feb., 1914, 42: 78-87; also Elementary Notes on Least Squares, etc., ibid., Oct., 1914, 42: 551-568.

for the probable error of the coefficient, where x is the departure of wind velocity from its mean and y is the departure of number of rainy days from its mean.

From these data the coefficient is found to have the value -0.42 ± 0.10. This is a fairly high value. It will be noted that one unexpectedly large wind movement occurred in connection with a large number of rainy days in August, 1915. This value is shown at "A" in Fig. 1. This high wind movement was the result of the hurricane during that month. If that month's record is omitted the value of the coefficient of correlation is found to be -0.56 ± 0.08, in which the coefficient is seven times the probable error.

Because the influence of extratropical cyclones has not yet ceased in June, and because of the frequency of tropical storms in this vicinity in August, the coefficient

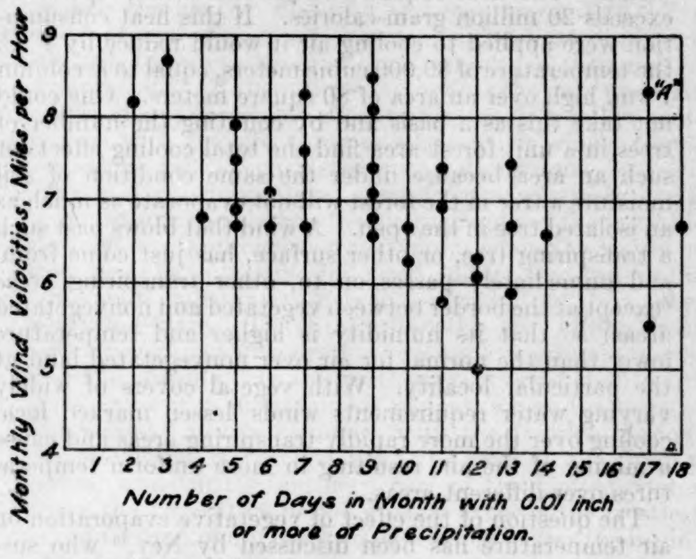


FIG. 1.—Relation between number of rainy days and wind movement in June, July, and August, 1910-1920, inclusive, at Houston, Tex.

of correlation has been computed for the month of July, for which the data are found in Table 1. The value for July is -0.65 ± 0.12, in which case the coefficient is higher and the probable error larger, which is to be expected.

TABLE 2.—*Average wind velocity, miles per hour, for each year, 1910, to 1920, inclusive, and the annual number of rainy days for the same period.*

Year.	Average annual wind.	Number of rainy days.	Year.	Average annual wind.	Number of rainy days.
	Mi./Hr.			*Mi./Hr.*	
1910	8.4	93	1916	8.4	87
1911	8.0	115	1917	8.6	69
1912	8.3	100	1918	8.2	93
1913	8.3	106	1919	7.7	126
1914	8.1	112	1920	8.2	113
1915	8.6	89			

From the values in Table 21 the coefficient of correlation is found to be -0.81 ± 0.07. This is positive assurance of a relationship, although the higher value is to be expected, on the assumption that there is such a relation, because of the longer period for which the averages were taken, being annual instead of monthly as in Table 1.

These values of the correlation coefficient [2] bear out the contention that the rains are more frequent in periods when the wind is light and also indicate that the season of convective rains sometimes extends into other months of the year.

TABLE 3.—*Average daily wind movement, miles per hour, of July, 1910–1920, inclusive, for days with rainfall of 0.01 inch or more and for days with rainfall of 1 inch or more.*

	Average hourly wind movement.
For all days	6.7 miles.
For days with rainfall, 0.01 inch or more	6.0 miles.
For days with rainfall, 1.00 inch or more	5.4 miles.

The averages in Table 3 prove beyond question that the wind movement is less rapid on rainy days and that the variation in the wind velocity is inversely proportional, to a certain extent, to the amount of rain.

The foregoing discussion is based upon surface wind movement. The wind in the lower levels of the atmosphere usually changes rapidly with altitude. The surface wind is not a reliable index to conditions aloft. If the above relation is true and it appears to have been established, it remains to study the relation between the wind aloft and the rainfall.[3]

With increasing height above ground the wind becomes more and more nearly constant. The wind at some distance above the surface is therefore a more reliable indication of the general air movements over the region in question. A knowledge of the wind aloft is therefore important.

CONCLUSION.

In the vicinity of Houston, Tex., where there is in summer abundant moisture and the temperature is persistently high, strong winds hinder the formation of local convective systems while any stagnant condition of the lower air is likely to produce frequent rains. A consideration of the general pressure distribution together with a study of wind movement aloft should enable the forecaster to predict convective rains with greater accuracy.

[2] In the MO. WEATHER REV., Feb., 1914, 42: 79, Prof. J. Warren Smith says: "It probably is safest to assume that there may be some relation if the correlation coefficient is three times the probable error and that the relation is established beyond question if it is more than six times the probable error."

[3] The vertical temperature gradient is important but little is known concerning temperatures aloft at Houston during the convective rain season.

THE EFFECT OF VEGETATIVE EVAPORATION ON THE RATE OF SEASONAL TEMPERATURE CHANGES.[1]

By RUY H. FINCH, Meteorologist.

[Dated: Weather Bureau, Washington, D. C., June, 1919.]

SYNOPSIS.

Data are given showing that the evaporation of water transpired from vegetation causes a definite local cooling. An attempt to show that vegetative evaporation affects large areas is made by comparing spring average daily temperature curves of continental stations in arid and humid regions. Four figures are given showing a flattening in such curves for the stations in humid regions with less flattening, or none at all, for the stations in arid regions. It is pointed out that several factors, among them the control of weather by HIGHS and LOWS, tend to obscure departures from a smooth curve caused by vegetative evaporation but the evidence seems to indicate that vegetative evaporation has an appreciable effect.

The effect of temperature on vegetal growth is well known but that vegetal growth, in turn, affects air temperatures has not received much attention. When one considers the immense quantities of water transpired from succulent plant growth and the amount of heat rendered latent by its evaporation he can not but be impressed by the thought that this phenomenon must have some appreciable effect on air temperatures. Quantitative values of the cooling effect due to vegetative evaporation over large areas are not easily determinable, for they are obscured by varying rainfall, soil moisture, and exposure to sunshine; by atmospheric circulation in HIGHS and LOWS; by variability of the seasons; and by all the effects of radiation and absorption.

It was found by Darwin[2] that the difference in temperature between two leaves—one freely transpiring and the other not at all—may amount to 1.5° C. Were it not for the fact that vegetation is a much better absorber of radiation than air we would expect to find, during the growing season, that all succulent portions of plants have temperatures appreciably lower than that of the air. It is to be expected, however, as has been confirmed by quantitative measurements by Seeley[3] and others that in sunshine the heating of plants, with moderate water requirements, due to the absorptive power of vegetation predominates over the cooling due to evaporation, and that parts of such plants exposed to direct insolation have temperatures considerably higher than that of the surrounding air—though obviously not as high as they would have were there no evaporation. From experiments conducted with sunflower plants it was computed by Brown[4] that if the transpiration loss of water were suddenly stopped during bright sunshine the temperature of the leaves would rise, for a short time, at the rate of 12° C. per minute. Briggs and Shantz[5] have found by careful and accurate measurements that the leaves of plants with high water requirements often have temperatures lower than the surrounding air even when exposed to direct radiation in clear, dry air. The amount of heat used by evaporation at time of maximum is for many plants well over one half of the total heat received from all sources.[4,6] "In some of the small grains the energy dissipated through transpiration is twice the amount received directly from the sun."[6] It should be borne in mind, too, that parts of most plants are shaded during a considerable portion of the day.

The loss of heat varies, of course, with the amount of water evaporated. The quantity of water transpired by many different plants is given in nearly all good textbooks on Botany or Plant Physiology. The daily transpiration of 22 of our common crops has been determined by Briggs and Shantz.[6] Accurate measurements of the amount of transpiration over large forested areas have never been made, though the estimates of many independent observers show very close agreement.[7,8] The evaporation from a single, small, isolated tree in the course of a day amounts, in many instances, to well over 36 kg. of water.[9] The heat required to produce this evaporation exceeds 20 million gram-calories. If this heat consumption were applied to cooling air it would reduce by 1° C. the temperature of 80,000 cubic meters, equal to a column 1 km. high over an area of 80 square meters. One could not take this as a basis and by counting the number of trees in a unit forest area find the total cooling effect for such an area because under the same condition of soil moisture a tree in the forest will not evaporate as much as an isolated tree in the open. A wind that blows past such a transpiring tree, or other surface, has just come from, and immediately passes on to, other transpiring areas (except at the border between vegetated and nonvegetated areas) so that its humidity is higher and temperature lower than the normal for air over nonvegetated land at the particular locality. With vegetal covers of widely varying water requirements winds lessen marked local cooling over the more rapidly transpiring areas and cause a mixing of the air, resulting in more uniform temperatures over different areas.

The question of the effect of vegetative evaporation on air temperature has been discussed by Ney,[10] who suspects that it has an appreciable effect and gives some theoretical values that are rather startling though computation shows that they hold for about all moist regions of the temperate zones and are much smaller than may be found over large sections of the eastern part of the United States that are well covered with vegetation. He computed that they average heat loss by evaporation in one day during the growing season from an area of 10,000 square meters (2.47 acres, 1 hectare) covered by some typical plant growths would reduce by 1° C. the following volumes of air:

	Cubic meters.
Pine forest	12,000,000
Grain (wheat, rye, etc.)	35,000,000
Meadow (timothy, clovers, etc.)	81,000,000

At the time of maximum transpiration these values are greatly exceeded.

Of the three general classes indicated above, grasses and clovers are the most potent dessicators of the soil and pine forests the least. Most broad-leaved trees, however, transpire several times as much water as conifers.[11]

The evaporation from the ground itself is, of course, considerable and increases with increase of temperature so long as the soil is very moist. Ney computed that the evaporation from the vegetative surfaces for the time and conditions mentioned above averages, for western Germany, 4 grams of water more per day over 1 square meter

[1] The author is indebted to Dr. W. J. Humphreys for assistance in the selection of this problem for investigation and for many helpful criticisms.
[2] Francis Darwin. *Bot. Gaz.*, Feb., 1904, vol. 37, No. 1, p. 81.
[3] D. A. Seeley. MO. WEATHER REV., July, 1917, p. 354; and *Mich. Acad. Sci.* 19th Rept., 1917.
[4] H. T. Brown. Fixation of Carbon by Plants, *Nature*, Sept. 14, 1899.
[5] From results as yet unpublished, but authority to quote given.
[6] L. J. Briggs and H. L. Shantz. *Jour. Agri. Res.*, vol. 7, No. 4, 1916.
[6] L. J. Briggs and H. L. Shantz. *Jour. Agri. Res.*, vol. 7, No. 4, 1916.
[7] Raphael Zon. Forests and Humidity, *Sci.*, p. 63, July 18, 1913.
[8] Ebermayer. Die physikalischen Einwirkungen des Waldes, etc., Aschaffenburg, 1873, S. 202.
[9] Vegetable Physiology; Green, p. 91; Plant Physiology; Duggar, p. 87, etc.
[10] C. E. Ney. *Met. Zeit.*, Dec., 1885, p. 445.
[11] Alfred Burgerstein. Die Transpiration der Pflanzen, Jena, 1904, p. 64.

than from the same land, moist, but with no vegetal covering. The normal rainfall for most of the stations studied in the following discussion, except where mentioned, varies but slightly during the time involved.

The growth of vegetation affects the temperature by three processes besides that directly due to evaporation: (*a*) Plant respiration similar to that of animals (most pronounced in the germination of seeds and in flowering)—giving off carbon dioxide and absorbing oxygen—an exothermic reaction; (*b*) the use of energy in the raising of water from roots to higher portions, and (*c*) the formation of carbohydrates, an endothermic reaction. The heat used by *c* is merely stored, becoming available later when the vegetal growth is used as fuel. The cooling due to *c* which is continuous during the growing season, but most pronounced during spring and early summer, greatly exceeds the heating due to *a* and may amount to 2 per cent[4] of that due to evaporation. The heat used in *b* amounts to only 0.0004 per cent, roughly, of that used in evaporation. Of these three factors *c* is the only one that produced an appreciable effect but it, too, is small in comparison with the effect due to evaporation which, therefore, alone will be considered in this discussion.

Vegetative evaporation starts from a relatively small amount some time before the average date of the last killing frost and approaches a maximum when the leaves of most trees have become full-sized and grasses and grains have made substantial growth, or within 30 days, say, from that date. The time after the last killing frost before vegetative evaporation reaches a maximum varies with the latitude. In the northern portion of the United States, except in mountainous regions, where the vegetative period[12] nearly coincides with the frostless period, the maximum is reached near the end of the 30-day period, while in the southern part of the United States where the vegetative period greatly exceeds the frostless period the maximum is apt to be reached nearer the beginning of the frostless period.

It is frequently noted that in passing abruptly on a hot, comparatively calm summer afternoon from a field of bare soil to land that is covered by succulent grass or clover a perceptible difference in temperature is encountered (in addition to that found on entering a forest). This is especially striking if the vegetal cover happens to be alfalfa or other plant with high water requirements.

There is plenty of evidence, therefore, that vegetative evaporation has some appreciable effect on air temperatures though whether it is sufficient to show through the other factors in control of temperature is not so obvious. We would expect, if the evaporation effect is sufficient, that it would tend to produce a flattening in the curve of average daily temperature, during the period above-mentioned, or that the temperature curve for an arid region would be steeper at this time than the curve for a corresponding humid region. In this connection one would have to consider the difference in slope due to any difference in the annual range of temperature between the arid and humid regions. Of course, vegetative evaporation lasts all season but, being continuous after once started, its effect on the slope of the temperature curve is not very noticeable except near the beginning and possibly at the time of defoliation, though in the autumn it decreases so gradually, as a rule, that its effect on the slope of the curve of average daily temperature is small compared with the effect produced in the spring.

To obtain some qualitative indications of this evaporation effect the average daily temperatures of stations in continental arid and humid regions having the same frostless period were compared. Figure 1 shows the somewhat smoothed curves of the average daily temperatures of Columbia, Mo., and Pueblo, Colo., from April 12 to May 31.[13] (The average date of the last killing frost is about April 21 for Columbia and a little later for Pueblo.) Both curves show a flattening about the last of April, while Columbia only has a pronounced change in slope. The flattening at Columbia persists until May 7, while the temperature at Pueblo rises rapidly from May 1. A large part of the curious cool period about the last of April at both stations is undoubtedly due to the effects of HIGHS and LOWS, which a very long record probably would lessen. The data upon which the curves are based are for the 30-year period ended 1918. Most of the marked irregularities for all stations studied are parallel and occur a day or so earlier in the western (arid) than in the eastern (humid) regions, which is to be expected if the irregularities are due to the movements of certain particularly effective HIGHS and LOWS. Pueblo, Colo., has considerable rainfall, and consequently some vegetal growth during the time covered by the curves and it is natural to suppose that the difference in the slope of the two curves is not as great as it would be for two stations having a greater contrast in rainfall and vegetation.

Figure 1 shows also the smoothed daily temperature curves for Birmingham, Ala. (humid), and El Paso, Tex. (arid), from March 16 to April 28, based on 23 and 31 years' record, respectively. The average date of the last killing frost for both stations is about March 29. The flattening in the Birmingham curve from March 29 until April 8 is very pronounced while El Paso shows an almost steady rise. The slope of the curve for Birmingham from April 9 to April 17 is steeper than for El Paso for the same period, which would be anticipated since the normal rise for Birmingham has been checked for so long a time; also the normal rainfall for Birmingham decreases quite rapidly from the latter part of March. This long continued flattening and subsequent recovery, similar to that found at several southern stations, somewhat obscures, with only moderate smoothing, the change in general slope of the curves that is so pronounced for all more northern stations whose records were studied.

Figure 1 shows further the mean daily temperature for Springfield, Ill., and El Paso, Tex., from March 1 to July 1. The rate of rise for Springfield is quite uniform until the last of April, when an abrupt change in slope, shown by the dotted line, occurs. No such change occurs in the curve for El Paso; in fact, the slope increases slightly after the curious cool spell of April 28 to May 3. The original curve for Springfield shows a flattening during the first few days of May, but as it occurs immediately after the cool spell above mentioned it is somewhat obscured. The change in slope at most of the other stations (see Table 1) in humid regions that were studied is similar and about of the same order of magnitude as that shown by Springfield.

As further evidence that the change in slope, however modified by other factors, is largely dependent on the growth of vegetation the curve for Columbus, Ohio, whose frostless period begins a little later than at Springfield and Columbia, is given (fig. 1) and compared

[4] H. T. Brown. Fixation of Carbon by Plants, *Nature*, Sept. 14, 1899.

[12] . B. Kincer. Relation between Vegetative and Frostless Periods, MO. WEATHER REV., Feb., 1919, 47: 106.

[13] The unsmoothed values for these curves were obtained as follows: The average of the maximum and minimum temperatures on Apr. 12, 1889, was added to that for Apr. 12, 1890, etc. . . . Apr. 12, 1918, and the total divided by 30. The same was done for all the Apr. 13ths, etc. No attempt was made to smooth the data by harmonic analysis, or by other artificial means to bring out any peculiarities in the curves. It is uncertain how deviations from a smooth harmonic curve should be interpreted. The curves and the discussion may speak for themselves. Even though they can provide no positive *proof* that the cooling effect of vegetative evaporation is responsible for an appreciable part of the temperature depressions cited, the curves, nevertheless, are in accord with what might be expected.—EDITOR.

with Amarillo, Tex. The pronounced change in slope at Columbus appears later, by about the interval anticipated from a consideration of the difference in the frostless period, than at Columbia and Springfield. Both curves show a change in slope, though that for Columbus is the more pronounced. The normal rainfall at Amarillo increases quite rapidly during the latter part of April and the first few days of May and during evaporation), no pronounced change in the slope of the average daily temperature curve due to the approach to the seasonal maximum would be expected until some time in June, whereas all stations in humid regions that were studied, except for a few mountainous ones with short records, show a pronounced change in slope within 30 days from the date of the last killing frost. The expected change in slope during June is shown in figure 1.

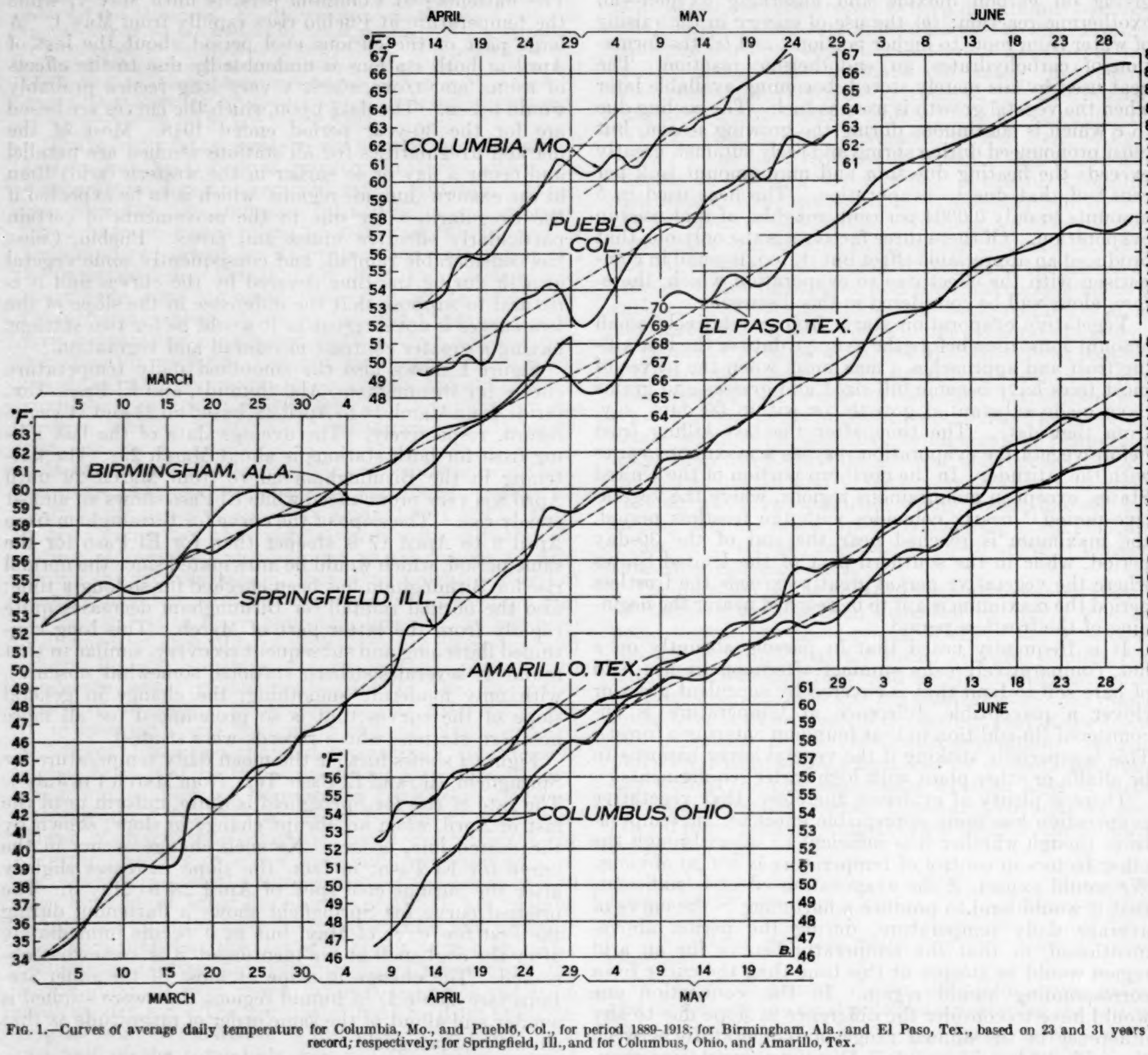


Fig. 1.—Curves of average daily temperature for Columbia, Mo., and Pueblo, Col., for period 1889-1918; for Birmingham, Ala., and El Paso, Tex., based on 23 and 31 years' record; respectively; for Springfield, Ill., and for Columbus, Ohio, and Amarillo, Tex.

the month of May has practically the same rainfall as Columbus. The transpiration from the grass and other vegetation in the Amarillo region is considerable during the time covered by the curves and the slight difference in the slope for the two stations is therefore not surprising. The record for Amarillo was used because of the scarcity of suitable stations in arid regions that have sufficiently long records.

From theoretical considerations, maximum insolation being received about June 21 and the further rise in temperature resulting from lag (neglecting vegetative

Table 1 gives the approximate average date of the last killing frost, the beginning of the vegetative period [14] and the beginning of the noticeable change in the slope of the mean daily temperature curve for some of the stations studied that have a record of 20 years or more.

Agreement with the above finding is shown in some of the many temperature curves drawn by van Rijckvorsel,[15]

[14] J. B. Kincer. Relation between Vegetative and Frostless Periods, Mo. Weather Rev., Feb., 1919, 47:106.

[15] E. Van Rijckvorsel. Konstant autretende secundäre Maxima und Minima. First part, 1905.

though the majority of the stations studied by him are not adaptable to this discussion on account of not having typical continental locations.

TABLE 1.

Station.	Approximate average date of last killing frost.	Approximate average date of beginning of vegetative period.	Beginning of noticeable change in slope.
La Crosse, Wis	May 5	Apr. 11	May 25
Harrisburg, Pa	Apr. 29	Mar. 23	May 6
Columbus, Ohio	Apr. 30	Mar. 21	May 7
Springfield, Ill	Apr. 25	Mar. 20	May 1
Columbia, Mo	Apr. 20	Mar. 19	Apr. 30
Pueblo, Colo	Apr. 30	Mar. 26	(1)
Lexington, Ky	Apr. 19	Mar. 12	Apr. 29
Raleigh, N. C	Apr. 4	Feb. 11	Mar. 25
Amarillo, Tex	Apr. 23	Mar. 6	Apr. 27
Birmingham, Ala	Apr. 1	(2)	Mar. 29
El Paso, Tex	Apr. 1	(2)	(1)

[1] No change. [2] Always 43° or above.

Atmospheric circulation in HIGHS and LOWS transport temperatures varying widely from day to day and when marked departures from the average occur with the same sign on the same day for several years the effects of evaporation are obscured. In any event, the evaporative cooling could not be clearly discernible in the records of any single spring. Arid regions on account of less cloudiness receive a greater amount of heat during the day than do humid regions but, on the other hand, they radiate more rapidly at night and, except for the more northern stations where the length of the day during the time involved greatly exceeds that of the night, these differences, presumably, roughly compensate one another. Vegetative evaporation increases the humidity of the air and with all the effects resulting therefrom tends to lessen the variability of temperature in humid regions from day to day. The amount of water thus evaporated at the time of maximum over any area well covered by vegetation is comparable to that from a water surface of the same area. As would be expected, therefore, the curves in humid regions are, as a rule, much smoother than in arid regions.

The distinct flattening so prolonged as that found at some stations was not expected and it may be that other factors were additive to the effect due to vegetative evaporation.[16] The seemingly premature falling off in the rate of temperature increase in humid continental interiors is what was expected would be found, and the evidence (in the light of the known absorption of heat by evaporation) that in such regions it is largely due to vegetative evaporation seems quite conclusive.

NOTE ON EVAPORATION FROM RESERVOIRS.[1]

The report of the committee of the Pacific Coast Electric Light and Power Association appointed for the collection of data on evaporation from reservoirs has recently been submitted. It contains a brief general discussion by the chairman, E. J. Crawford, and is accompanied by papers on the subject of evaporation from reservoirs,[2] by C. H. Lee, C. E. Grunsky, and N. W. Cummings.

In the report of the chairman it is noted that evaporation is apparently less variable than other meteorological phenomena, such as rainfall and temperature, and that the larger portion of the evaporation loss from a reservoir occurs during the summer months.

Mr. Lee concludes that the evaporation from a water surface or from a floating pan is about two-thirds that from a land-exposed buried pan. It is his opinion that for purposes of the hydraulic engineer, floating-pan evaporation observations, if properly made, are the most reliable for reservoir calculations, and a list of precautions which should be observed in obtaining such records is given. These include the following:

The pan should have a surface area of at least 9 square feet and a depth of about 12 inches. It should be fully protected from splash by means of a raft, or otherwise. The water in the pan should be kept clean and at a level approximately the same as that of the surrounding water, and it should be located in deep water and at a sufficient distance from the shore line or other objects to insure normal wind and humidity conditions. Nothing is given as to the effect of the raft in breaking upstream-line flow of the wind, and prevention of the formation of a normal vapor blanket over the floating pan, such as probably exists to some extent at least over the free water surface.

Mr. Grunsky points out, as others have done, that the controlling factor which influences the rate of evaporation from an open body of water is temperature. An empirical formula is given for calculating evaporation in terms of temperature alone. This discussion seems to require the qualification that while the evaporation rate from a given body of water may be expressed fairly accurately, at least as a function of temperature, yet the relation determined for one locality may not, and generally will not, apply with equal accuracy to another location.

Mr. Grunsky points out that in determining the probable loss which will occur from a proposed reservoir through evaporation, present existing data must, in general, be depended upon, since the actual loss can not be measured by pans or other methods until the reservoir is constructed. This observation suggests the importance of further development of methods of correlation of evaporation loss with the factors by which it is controlled, so that it may be possible either to calculate evaporation from existing and widely distributed meteorological data, or so that rational corrections can be made to existing evaporation records so as to render them applicable to a particular location.

Mr. Cummings takes up the problem of determining evaporation losses from a heat balance equation. Theoretically, evaporation loss during a given time-interval can be measured through the amount of heat lost by evaporative processes. If, therefore, the heat supplied to the water during the interval, the gain or loss of heat stored in the water, and the loss of heat through radiation, conduction, or other processes than evaporation, are known, the heat consumed in evaporation and the evaporation itself can be determined. Practically, data for such calculations are almost wholly wanting.

The problem of determining evaporation from a heat balance equation has recently been discussed in a published paper by Ångström, in which such data as are at present available for determination of the various factors in the heat balance equation are presented.[1] It is unnecessary, therefore, to review Mr. Cummings's paper, covering similar ground, at length.—*R. E. H.*

[16] For example, an increase in cumulus clouds would delay the rise of the temperature curve in spring.—EDITOR.

[1] Report of subcommittee of the Pacific Coast Electric Light and Power Association for Collection of Data on Evaporation from Reservoirs, presented at meeting in San Francisco, Feb. 18, 1921.

[2] Already published, or to be published, in the *Journal of Electricity*.

[1] Ångström, Anders: Applications of heat radiation measurements to the problems of the evaporation from lakes and the heat convection at their surfaces. *Geografiska annaler*, 1920, H. 3.

WEATHER-FORECASTING MEETING OF THE NATIONAL ELECTRIC LIGHT ASSOCIATION IN SAN FRANCISCO.[1]

By E. A. BEALS, Meteorologist.

[Weather Bureau, San Francisco, Calif., Mar. 19, 1921.]

On February 18, 1921, the National Technical Section of the National Electric Light Association, under the auspices of its Pacific Coast Geographic Division, held a meeting at San Francisco, devoted to discussions of weather forecasting. The chairman of the meeting, Mr. H. A. Barre, in his opening address said, in part:

> As we stand now every additional ton of agricultural products produced in California, and every additional ton of industrial output produced must come from the use of electric power, and the development of that power, in some measure, conflicts with the use of streams for irrigation.

Mr. Barre further explained that the feeling that engineers in general were not sufficiently acquainted with meteorological and climatological relations to water supply was the main thing that prompted this convention to consider forecasting problems.

The first paper presented was by Dr. W. E. Ritter, director of the Scripps Biological Institute. He stated that he was a member of a committee that is undertaking an international survey of the Pacific Ocean, embracing the subjects of oceanography, meteorology, and hydrology. Dr. Ritter expressed his conviction that so far as California, Arizona, and New Mexico are concerned the water supply is the limiting factor in determining the size of the population that can be supported in those States. Hence every energy should be directed toward a thorough investigation of the water supply, which of course is ultimately a matter of precipitation.

The next speaker was Mr. E. A. Beals, district forecaster of the Weather Bureau at San Francisco, who addressed the meeting on "Long-Range Weather Forecasting." This paper lays particular stress on the possibilities of making long-range predictions of rainfall for the Pacific coast. Attention is called to the necessity of more extended study of the behavior of the Aleutian center of action, as off-shoots coming from it apparently cause the greater part of the rainfall of the Pacific States. While expressing the opinion that there is no immediate prospect of successfully solving this problem, Mr. Beals feels it may be eventually solved to the extent of answering the practical purposes of engineers and others interested in this problem of weather forecasting.

In conclusion the speaker informed the convention of the great interest of the Chief of the Weather Bureau in the efforts to develop long-range forecasting to a point where it may be of practical use, and of his advice that very long weather records be examined carefully by statistical methods before attempting practical applications.

Father Ricard told of the occurrence during recent years of a LOW or a HIGH on the Pacific coast simultaneously or within a day or two of the time when a sunspot crosses the central meridian in the northern or the southern hemisphere, respectively, of the sun. He urged the improvement of rainfall forecasting by the use of daily observations of the electric state of the atmosphere as well as by further studies of sunspots and oceanography.

Mr. B. M. Varney, of the Department of Geography, University of California, followed with an address on "The Distribution of Precipitation in Washington, Oregon, and California." He reminded the convention that the Weather Bureau some time ago classified the system of low-pressure areas on the Pacific coast into the north Pacific type and the south Pacific type. The LOWS entering from the north Pacific pursue an average path (subject to wide variations) carrying the centers of low pressure over the Puget Sound country, while those of the south Pacific type have an average entrance somewhat north of Point Conception. Mr. Varney points out that the regional distribution of rainfall in California is very largely a matter of the frequency of these two types of pressure activity.

The subject of variation of precipitation with change in altitude is treated quite fully by the author.[2]

"Snowfall with Particular Reference to California," by Mr. A. H. Palmer, of the San Francisco Weather Bureau office, in the absence of Mr. Palmer was read by Chairman Barre. The following paragraphs give the scope of the paper:

> The snow deposits in the mountains of California have recently come to be recognized as one of the most important natural resources of that richly endowed State. Snow is a natural storage reservoir and upon melting forms (1) the only source of supply of irrigation water, without which there could be no extensive agriculture, and (2) a means of developing hydroelectric power, upon which the State's industrial future is largely dependent. When the nation's coal reserves are exhausted and the rapidly diminishing oil supply has been depleted, the potential energy contained in the elevated snow fields of the West will case a westward migration of industry, a movement which has already begun.
>
> The heaviest snowfall in North America is found in the higher portions of the Olympic Mountains of Washington, the Cascades of Oregon, and the Sierra Nevada of California. It is not unusual for depths of 50 feet or more to accumulate on the ground at one time. While snow as it falls is ordinarily about 10 per cent water, by volume, that which accumulates on the ground packs and solidifies because of pressure and through alternate thawing and freezing. The great snow deposits found in spring are 30 to 40 per cent water, by volume, and through slow melting in summer form the only water supply, as the summer half-year is practically rainless in California.
>
> Because of improved methods of transmission, hydroelectric power is now conducted 200 to 300 miles to market. Nearly all the hydroelectric trunk lines in California run from north to south. Some of the power consumed in the San Francisco industrial region comes from the melting snows of mountains along the California-Oregon boundary.
>
> For measuring snowfall the difficult problem is that of securing a proper catch. The most satisfactory instrument devised for this purpose is the Marvin Shielded Rain and Snow Gage, a massive instrument designed by Prof. C. F. Marvin, Chief of the United States Weather Bureau. It is 9 feet in height, and about the mouth of the cylindrical can, which forms the gage proper, there is a double arrangement of wind shields. For determining the density of snow on the ground, the most satisfactory instrument is the snow sampler, first used extensively by Prof. J. E. Church, of the University of Nevada, and subsequently improved and perfected by Mr. B. C. Kadel, of the Weather Bureau. The sampler is a metal tube which is plunged through the snow to the ground, and the snow column thus secured is subsequently weighed by means of a spring balance.
>
> In view of the rapidly diminishing coal and oil reserves, it behooves us of the present generation to make a more nearly complete use of the vast energy now going to waste in our unharnessed streams. Future generations will not hold us guiltless if we continue to consume the limited coal and oil supply and allow the limitless energy of mountain streams to go to waste.

The evening session of the convention began promptly at 8 o'clock, and the first paper was entitled, "Scientific Long-Range Weather Forecasting" by Dr. Charles F. Brooks. Owing to his absence this was read by Chairman Barre and received with rapt attention.

Dr. Brooks is quite optimistic regarding the possibilities of making dependable long-range forecasts. He

[1] To be published in full in the proceedings of the National Technical Section, Pacific Coast Geographic Section, National Electric Light Association.

[2] Varney, B. M. Monthly Variations of the Precipitation-Altitude Relations in the Central Sierra Nevada of California. (2 figs.) MO. WEATHER REV., Nov., 1920, 48: 648-650.

takes the ground, however, that "the Weather Bureau can not experiment at public expense upon the public itself" and until a sufficiently sound, scientific basis has been reached the Weather Bureau would not be justified in attempting to make forecasts of this character.

Dr. Brooks said:

The long-range forecast goes beyond the realm of storms already in existence and which by their movement may be likely to affect us some time next week. Its success or failure depends on weather features yet to be born. Long-range forecasting, therefore, has but little in common with day-to-day forecasting, or even with forecasting on Saturday what the general character of the weather during the coming week will be.

He cited methods now in operation in India and Java, based in the former case upon the distribution of pressure affecting the southeast trade winds and their continuation into the summer monsoon winds; and in the latter case upon modifications of three-year periods of local pressure, winds, and rainfall. Besides these examples, Dr. Brooks thinks long-range forecasts are possible, "in view of what we know about the sequence of the weather, the periodicity of solar changes, and the relations between weather in widely separated parts of the earth."

In discussing these points great stress was laid upon the fact that sequences in the weather are not wholly fortuitous. They may come, he thinks, as the result of accumulation of slowly changing forces to a point where the existing balance of weather is overturned. Or they may appear as a result of a marked dimunition in the absorption of solar radiation into the earth's atmosphere over a considerable area, owing to changes in reflection, if not to actual changes in heat arriving from the sun.

Periodicities in weather were mentioned for such short intervals as a week, a fortnight, or 4 weeks, also for longer ones; such as, 8 months, 2 years, about 3 years, 5½ years, 7 years, 11 years, and 33 to 35 years. These, he says, are interesting, for almost without exception there seem to be corresponding solar periods, though in the case of the shorter ones they are uncertain.

Dr. Brooks agrees with Köppen, Walker, Helland-Hansen & Nansen, and others that fluctuations in the weather for some of the periods bear a close relation to solar activity, but he thinks until this relationship is more closely established, it is impracticable to make long range weather forecasts from our present knowledge regarding changes taking place in the amount of heat received by the absorption from the sun. Another drawback to predictions of this character would occur through our not being able to forecast the solar changes, as Dr. Brooks thinks they meet with some immediate response in the mobile atmosphere, though there are others who think they act more slowly by affecting the centers of action, and these in turn the weather at distant points perhaps several weeks or months afterwards.

In his discussion of the occurrence of similar or opposite abnormalities in the weather of widely separated parts of the earth simultaneously or a few months apart, he says it is suggestive of not only the unified response of the atmosphere to any major influence, but also of delayed reactions, dependent perhaps, largely on the slowness of travel of ocean waters.

After describing how the ocean waters are warmed and cooled above their averages for different latitudes by a change in wind direction or an increase in wind velocities, he stated these effects can be traced for many months to far-away regions and it is therefore possible to base seasonal weather forecasts upon ocean surface temperatures.

Dr. Brooks cited a hypothetical case, where a body of unusually warm water coming through the Strait of of Florida would in 8 or 10 months influence the weather off the west coast of Europe, and prior to this affect the weather when passing north and northeast off the east coast of the United States.

While declaring long range forecasting from ocean temperatures would be a complex and laborious practice, he feels that there would be few who would hesitate a moment on this account, as the value if successful would repay many times over the cost of their preparation.

In conclusion, Dr. Brooks emphasized the need of learning more about the changes in the sun and their relation to changes in the weather, and above all the importance of gathering more information about the weather of the world.

He said:

For the vast expanse of the ocean, covering three-fourths of the surface of the globe, we must rely on the few ships, which do not cross all regions, but most of which keep to rather narrow lanes. Just consider these figures: The Weather Bureau receives from the whole North Atlantic but 100 or 200 observations per day, and only half as many from the North Pacific. For all the other oceans the score or two of daily observations is approximately equivalent to an average of one for every 3,000,000 square miles, or an area approximately equal to that of the United States. What would we know about the weather of the United States if there were but one station reporting each day and the same station probably never reporting twice in a year, or perhaps even in 10 years?

The meteorological analogy of southern California, southwest Africa and west Australia and the narrowest of the Atlantic and Indian Oceans, in comparison with the Pacific, might similarly make it worth while to look for indications of California rainfall in the rainfall of those distant regions. Furthermore, with the aid of correlations found for parts of Europe as guides for corresponding investigations in the Pacific, correlations with a delay of a few months may be found to give indications of the seasonal weather to be expected here. But however successful these may be, they could not compare with what could be done with accurate knowledge of the weather and surface temperature conditions of the North Pacific Ocean. That region seems to be the breeding place for weather types of the Pacific coast of the United States, therefore, that is the region which we must study in order to say when there will be a drought and when there will be floods in the Pacific States.

Following Dr. Brooks, an illustrated lecture on, "Indications of Seasonal Variations of Weather in the Growth of Rings of Trees," was given by Dr. A. E. Douglass, director of the Steward Observatory, University of Arizona.

He stated:

This work on tree rings, which I have been interested in for a great many years, is, you understand, a study that is not yet finished, and as it were, I am giving you a sort of report of its present condition.

Dr. Douglass' own synopsis is as follows:

The data here given were obtained in the identification and measurement of more than 100,000 rings in some 400 different trees. The trees included groups of Douglas firs from Oregon, *Sequoia gigantea* from California, yellow pines from Arizona and Colorado, hemlocks from Vermont, and Scotch pines from northern Europe. Many trees have systems of rings that show the influence of climatic conditions. For example, the yellow pines growing near Prescott, Ariz., give a rainfall record with an accuracy of 70 per cent. A slight conservation formula which recognizes different states of activity of the trees raises this correlation to 85 per cent. The giant sequoias show some relationship to the rainfall at Fresno and other points in the great California Valley. It is regretted that full weather records are not being taken in the immediate vicinity of these giant and aged trees.

Many cycles are exhibited by the trees, of which the most pronounced is the sunspot cycle or some of its harmonics. The trees around the Baltic Sea exhibit a pronounced rythm whose maximum occurs at sunspot maximum. The cone-bearing trees in the moist climates of this country, so far as tested, also show the sunspot cycle conspicuously, but with a difference in phase from the European trees. The pine trees of northern Arizona show the half sunspot cycle in a pronounced manner. The variation of these pines from the year 1400 to 1550 and even 1650 is one of the most marked cases of rhythm

which I have observed. The double sunspot period of about 22 years is conspicuous in the Arizona pines, and the triple sunspot period shows in them for the last 200 years. Both these multiples of the sunspot cycle are found also in the European trees. Of longer periods one extending a little over 100 years in the Sequoias and in the pines is the most conspicuous.

An instrument called the periodograph has been designed along optical lines for the purpose of analyzing any plotted curve into its component periods. This instrument does not readily give the harmonic constants, but it does give the periods existing in almost any complex mixture. The use of this instrument has confirmed the cycles mentioned above. When applied to the 3,000 years of the growth record of the Sequoias it gives some very interesting facts. First, that this form of analysis promises to be of assistance in outlining meteorological districts of homogeneous character. Second, that the sunspot cycle of a trifle over 11 years was existing 3,000 years ago. Third, that different centuries have probably been characterized by different combinations of climatic cycles. This will very likely assist in solving some archaeological problems, and in fact, the study of growth rings in prehistoric timbers has already given valuable information in regard to primitive construction of buildings.

The chief use of the evidence in trees in the matter of climatic cycles is a verification of the existance of those cycles over long periods, and a chance of studying them to great advantage with the analyzing instruments above referred to.

After a brief discussion of the lecture by Dr. Douglass, the meeting was addressed by Dr. Geo. F. McEwen, of the Scripps Institute, who, after describing the scope of oceanography and the circulation of ocean currents, gave some specific results of work that has been done in the Pacific. He stated:

While conducting a continuous investigation of certain oceanic phenomena at the Scripps Institution pier, near La Jolla, southern California, a relation was indicated between sea temperatures observed during the summer months and the amount of rain falling during the following winter months. This continuous series of observations began in 1916, and up to the present time (October, 1920) indicates that the lower the summer temperature, the higher will be the rainfall in southern California during the following winter.

While it would be surprising if such a simple empirical relation as has been found for so short a time interval should continue to hold thus accurately in the case of as complex a system as the ocean and the atmosphere, it seemed advisable to call attention to the result, owing to the great advantage in using all possible means for obtaining some indication of the coming rainfall.

Dr. McEwen illustrated by means of graphs a correlation he had discovered between the temperature of the ocean and fog near its shore. He showed that between Point Arguello and San Diego the fog was least where the departure of the temperature of the ocean surface was least below normal and greatest where the temperature departure was the most below normal. These differences below normal of ocean temperatures, he thinks, are proportional to the barometric gradient from the center of the permanent North Pacific high-pressure area, and as the meteorological conditions are related to the pressure conditions, and the pressure conditions are reflected in ocean temperatures, there may be a means through the study of the ocean temperatures of getting at some of the meteorological changes, and possibly making predictions.[3]

After a short discussion, a paper entitled, "The Problem of Seasonal Weather Forecasting," by Maj. E. H. Bowie, was read by Mr. Armstrong. Mr. Bowie stated that meteorology has for its goal the making of accurate forecasts of wind, weather, and temperature for long periods in advance. The making of such forecasts has for years received consideration from meteorologists of good repute, as well as from others not wholly scientific in their understanding of the question. The latter, he thought, have been a hindrance rather than a help to those of honest endeavor engaged in solving this difficult problem.

[3] The paper published in *San Diego Farm Bureau Monthly*, Jan.-Feb., 1921, 7:1, 4.

Mr. Bowie, in mentioning the study that has been given the frequently marked deviation from the normal in meteorological elements, cycles, sunspots, and variations in the solar constant, says that all so far have failed to bring forth a working hypothesis capable of leading the way to the making of forecasts of sufficient accuracy to be of value.

As nothing definite has been evolved after so much painstaking study, he thinks the right combination has not yet been found, or else the records studied do not cover a sufficient length of time really to get at the facts in the case. If the records are too short to develop periodicities, or if it should happen there is none, we should not give up, as he thinks long-range forecasts may possibly be made after a better understanding has been obtained regarding the primary circulation of the winds of the earth's atmosphere.

This circulation is subject to marked deviations from the normal, which are brought about by influences that are world-wide in their operation. In illustration, Mr. Bowie says:

We know that abnormally high pressure off the California coast and low or relatively low pressure over Alaska and the Aleutian Islands will give a minimum of rainfall in southern California, and that the seasons of plus deviations from the normal are associated with high pressure over the interior of Alaska, a southward extension of the semi-permanent winter LOW over the Aleutian Islands, and at the same time a breaking down of the high pressure off the California coast. The inference is that under the latter condition the lower air strata in the eastern Pacific flows up the west coast of Mexico and, gradually losing temperature and becoming supersaturated, give the wished-for rains, while under the former condition the winds off southern California are from the northwest, and, moving southward and becoming warmer, depart more and more from a state of saturation.

Mr. Bowie is of the opinion that a thorough study of the "tendencies" of the general circulation over the Pacific Ocean and Asia preceding the beginning of the rainy season will lead to important conclusions concerning rainfall in California, and the thing to do is to outline means for procuring the information wanted.

This, he says:

will entail the gathering and compiling of observations from all points within and bordering on, and from vessels sailing on the Pacific Ocean. A by no means small task, but it would be worth while; moreover, this will be a step toward the preparation of daily, seasonal, and yearly charts of the atmospheric conditions of a world-wide nature. Perhaps when such charts become available for study purposes many of the problems confronting meteorology will be possible of solution.

Owing to lack of time, Prof. Henry's paper, on "Long-Range Forecasting," was not read at the meeting, but was submitted and will appear later in the printed proceedings of the convention.

Prof. Henry's paper contains a large amount of historical matter relating to the subject which is interesting, but not of a character to promise hopeful results. He agrees with Maj. Bowie that the most promising avenue of approach to the problem of seasonal weather forecasting is a better understanding of the pressure distribution over the globe. This, he says:

is not a question of the pressure distribution over a single geographic unit, but rather the world-wide distribution must be forecast before we may hope to indicate what type will prevail in the United States, for example.

There is evidence, he says:

that the pressure distribution over the Canadian Northwest, including Alaska and the Pacific, westward from the continent some hundreds of miles, exerts a profound influence upon American weather, particularly that of the western United States. In like manner the pressure over the middle western portion of the middle North Atlantic, in conjunction with the pressure over northwestern Canada, exerts a strong influence upon the weather in the eastern part of the country. Manifestly, then, in any rational scheme of long-range weather forecasting it is

necessary to determine in advance what type of pressure distribution will prevail throughout the season.

Differences in pressure on the earth's surface, Prof. Henry said:

are largely dynamic results due to motions of the atmosphere, and likewise the areas of high barometer and low barometer, respectively, may also be largely due to the aforesaid motions, but the ultimate cause of their formation is due to differences in the density of the atmosphere, which in turn are due to differences in temperature and moisture distribution.

Because of the importance of these motions causing changes in the character of the high and low barometric areas over the north Pacific Ocean, Prof. Henry thinks there is need above all else of more well established facts concerning the weather conditions which result from them. These facts are not at hand, and hope of obtaining them rests largely in the rapid multiplication of ship observations throughout the vast expanse of the Pacific Ocean.

Should these be forthcoming, he says:

It may be possible to discover the preliminary symptoms of the changes in position and intensity of the Pacific HIGH, which, if accomplished, will be a forward step toward the goal.

Prof. Henry does not believe that an examination of rainfall records of the past would be worth while, as a comprehensive analysis has already been made of many of them without discovering any periodicities that could be used for forecasting purposes.

He does not think the matter is definitely settled in the negative, but believes we must wait upon civilization and settlement in unrepresented districts for further observations, and when they are obtained additional light will be thrown upon that which is now obscure. Our best efforts in the meanwhile "should be directed toward the enlistment of more and more ship captains in the meteorological service."

SEASONAL FORECASTING OF PRECIPITATION—PACIFIC COAST.[1]

By ALFRED J. HENRY, Meteorologist.

[Weather Bureau, Washington, Mar. 8, 1921.]

SYNOPSIS.

An examination is made of the observational data of past years bearing upon the subject. This examination shows clearly that the distribution of precipitation in Pacific Coast States is not, as a rule, of the same order of intensity, indeed fairly heavy precipitation in Washington and Oregon may be associated with deficient rainfall in California, and vice versa. The physical grounds for the difference in distribution are next sought. Three classes of seasonal distribution are distinguished, and these in turn are discussed with reference to their probable causes.

The conclusion is reached that a knowledge of the pressure distribution over the northeastern portion of the Pacific Ocean and the Canadian Northwest affords the most hopeful avenue of approach to a rational solution of the problem.

The annual precipitation in Pacific Coast States ranges from a few inches in extreme southeastern California to more than 100 inches in the foothills of western Oregon. There is thus a very pronounced increase in precipitation with increase in latitude, which is more noticeable in California than in either Washington or Oregon. The greatest contrasts, however, are those between the precipitation of the lowlands and that of the mountain masses which parallel the great interior valleys. This contrast is greater on the leeward than the windward side of the higher mountains.

Perhaps nowhere in the North American continent is the seasonal character of the annual precipitation so conspicuous as in California, where more than 50 per cent of the annual precipitation occurs in the three winter months of December to February, while the months of June to September are practically rainless, except upon the higher mountain summits.

Statistics available.—The most readily available statistics for the region under consideration are those found in Table 1 of the MONTHLY WEATHER REVIEW. This table, in very nearly its present form, was begun in the last half of 1884; at that time it bore the heading "Table of Miscellaneous Meteorological Data, Signal Service Observations" in the beginning the monthly departures were not known. It is fairly complete in the last respect after 1892, although strictly speaking the homogeneity of the record is not as great as could be desired. The exigencies of the service at times made it necessary to discontinue an observing station or to remove it a short distance from its original location. Most of the changes in the observing stations that took place during the 29 years considered were of that order. The original stations in the north Pacific coast region were: Fort Canby, Neah Bay, Olympia, Port Angeles, Tatoosh Island, Wash., and Astoria, Oreg. For the middle Pacific coast region in 1892, the following named stations were used: Eureka, Point Reyes, and San Francisco, all on the coast, and Red Bluff and Sacramento in the interior. The south Pacific coast region was represented by the stations at San Diego, and Los Angeles one of which is on the coast, the other but a short distance therefrom. The interior of southern California was represented by the station at Fresno. The original table above referred to gives the mean precipitation for the month for each of the three districts and the departure from the normal the latter being computed from those records of 10 to 20 years in length. I have combined the departures from the normal of the three winter months, into a single expression which represents the abnormality of the winter as a whole beginning with December, 1891, and continuing through until February, 1920; thus in Table 1, which immediately follows, the figures 2.5 inches, 2.9 inches, 2.9 inches in the columns headed "North," "Middle," and "South," respectively, indicate that precipitation for the winter 1891–92 was deficient by these amounts in the respective districts. The full-faced figures indicate positive departures, while negative departures are printed in the ordinary type. These figures are obtained by adding algebraically the departures of the three winter months; they represent, therefore, the total or accumulated departure and not the mean departure.

TABLE 1.—*Winter precipitation departures—Pacific Coast States.*

[Accumulated departures in inches and tenths.]

Years.	North coast.	Middle coast.	South coast.	Years.	North coast.	Middle coast.	South coast.
1891–92	2.5	2.9	2.9	1906–7	3.8	2.7	2.9
1892–93	4.0	1.7	1.5	1907–8	0.5	1.3	0.9
1893–94	3.0	1.8	2.7	1908–9	1.6	8.6	5.6
1894–95	7.1	5.4	3.2	1909–10	3.2	3.2	2.0
1895–96	9.5	3.3	4.2	1910–11	5.2	2.3	3.6
1896–97	2.4	0.8	1.5	1911–12	2.8	6.0	4.5
1897–98	3.8	6.4	5.4	1912–13	3.4	6.9	1.5
1898–99	2.6	6.2	4.7	1913–14	0.5	5.1	6.6
1899–1900	2.3	3.6	5.2	1914–15	8.6	7.4	6.6
1900–1901	2.0	0.2	0.6	1915–16	3.5	6.0	8.1
1901–2	1.2	1.3	3.2	1916–17	6.3	1.8	2.7
1902–3	1.9	3.0	1.1	1917–18	5.7	3.9	1.0
1903–4	2.0	2.5	4.4	1918–19	1.4	0.5	1.6
1904–5	4.8	4.1	0.5	1919–20	8.5	8.6	2.6
1905–6	3.8	2.9	2.0				

Negative departures in ordinary type, positive in full-faced type.

[1] This is a discussion of the specific problem of long range forecasting for the Pacific coast. It is not identical with the paper by the same author mentioned in the preceding article.—*A. J. H.*

Remarks on Table 1.—The figures of the above table show the seasonal distribution of the precipitation for each of the 29 years, the magnitude as well as the sense of the departures. It will be noted that the distribution about the mean is not symmetrical, there being more seasons with negative than positive departures, but since this is a general characteristic of rainfall distribution elsewhere no particular significance is attached to it. The standard deviation has been computed for each district; the figures are as follows:

	Inches.
North Pacific	±2.97
Middle Pacific	±1.67
South Pacific	±1.24

In but 2 of the 29 years, or 7 per cent of the time, was the departure uniformly positive in all three districts and in but 9 of the years was it uniformly negative. In the remaining 19 years a mixed distribution obtains.

There seems to be a fairly sharp dividing line between the north and middle Pacific regions, respectively, in the matter of seasonable distribution, with a tendency for years of like character to repeat, occasionally. See the group of years 1896–1899 with positive departures in the north Pacific and negative in both the middle and south Pacific. See also the two groups of years 1907–1909 and 1914–15, in both of which the first and second years show an excess in the southern regions, followed by an excess in the third year in all three districts. This sequence might indicate that the meteorological conditions favorable to precipitation developed progressively, reaching a climax in the third year, and again it may be a purely fortuitous occurrence.

It will be noticed that the distribution of the departures about the mean is not symmetrical, there being but 33 positive departures and 54 negative, or 38 and 62 per cent respectively. This, however, is a world-wide characteristic of the distribution of precipitation. I have found a similar characteristic to attach to departures of mean pressure from the normal, there being more positive than negative departures in all of the cases thus far examined. Since high pressure is inimical to the occurrence of precipitation there may be a closer bond of union between the two phenomena than has hitherto been suspected.

There appears to be sufficient physical grounds for the distribution of precipitation as shown in the above table; I shall now consider some of them in detail.

WET AND DRY SEASONS ON THE PACIFIC COAST.

I distinguish three classes of wet winters on the Pacific coast, viz, (1) those which give heavy rains in all of the States, particularly in California, (2) those in which the rainfall is deficient in Washington and Oregon and in excess in California, and, finally, (3) those in which the reverse is true.

In each case the general control is doubtless the pressure distribution in that part of the globe embraced by the eastern Pacific and the western half of the North American continent. This part of the earth's surface contains two of the so-called great centers of atmospheric action, viz, the Aleutian LOW and the Pacific HIGH. The first named is a pronounced feature of the winter circulation only and is known to vary both in its intensity and the geographic position it occupies from season to season, although the law of variation is not known. The exact position of the Pacific HIGH is known from ships' observations only; and while it too is known to shift its position slightly from month to month, its variations in latitude and longitude are not so well known as those of the Aleutian LOW.

The precipitation of Pacific Coast States is great or small according as to whether areas of low pressure enter the continent and move eastward in low or high latitude. In years of deficient precipitation in California the LOWS of the month or season will be found to have entered the continent and moved eastward north of the mouth of the Columbia River.

In years of abundant precipitation the movement of areas of low pressure is east or southeast, passing inland south of the mouth of the Columbia. This is, however, a very broadly generalized statement and must be interpreted accordingly.

I shall now consider more in detail the conditions which are associated with the several types of wet winters on the Pacific coast beginning with NO. 1—a wet winter in all of the States.

This type is represented by the winters of 1909 and 1916, each of which included at least one month of exceptionally heavy precipitation—so heavy in fact as to give character to the whole winter. The particular point to which I desire to call attention is that the heavy rain is rarely continuous throughout the entire season but is more likely to be concentrated in a period of a month or slightly longer, the remainder of the season being relatively dry. January, 1909, had the largest number of rainy days at San Francisco, Calif., during a period of 60-odd years. The explanation is found in the daily weather maps of the month. From these it can be seen that the Aleutian LOW evidently extended to the coast of the North American continent south of latitude 45° on many days of the month. In 1895, I had occasion to remark:[1]

> * * * The storms of the Pacific coast present a characteristic that is worthy of special study, viz, an apparent oscillation from the ocean to the land and vice versa, that is to say, the LOW approaches the coast and partially disappears, reappearing within 12 to 36 hours, and continuing this action until the storm finally disappears.

In the light of evidence that has come to hand within the last 25 years it is evident that the LOWS which approach the coast in the neighborhood of north latitude 45° are not always separate and distinct entities but rather merely manifestations of the great Aleutian LOW whose center is probably somewhere over the Gulf of Alaska, several hundred miles from shore. At times offshoots from this LOW pass inland over the continent, some of which eventually reach the Atlantic. In January, 1909, while but three individual LOWS passed inland the presence of the southeastern front of the Aleutian LOW off the coast was the cause of the nearly continuous rains in California. Another effect of the presence of this LOW was to modify profoundly the pressure distribution of the United States as a whole. The Great Basin HIGH,[2] characteristic of dry weather in California, was wholly absent, as it also was in January, 1919.

Considering now winters of the second class, viz, those with deficient precipitation in Washington and Oregon and normal or above normal in California, it is found that high pressure in Alaska, which causes easterly winds in the region north of the Columbia River, is prejudicial to rains in both Washington and Oregon; California, on the other hand, being in the region of light and variable winds, is generally well watered since, paradoxical as it

[1] MO. WEATHER REV., Jan., 1895, 23: 3.

[2] The term "Great Basin" as used in this paper refers to the northern portion of the western Cordilleran region which is characterized by wholly interior drainage. Roughly speaking, as here used, it comprises southeastern Oregon, southern Idaho, southwestern Wyoming, northern Utah, and northern Nevada. Representative Weather Bureau stations within this area are Salt Lake City, Utah, Winnemucca, Nev., and Boise, Idaho.

may seem, high pressure in Alaska, which is prejudicial to rain in Washington and Oregon, is favorable to rain in California, since one effect of the high pressure is to cause areas of low pressure to enter the State at a relatively low latitude and thus to cause moderate rains.

The third class—wet in Washington and Oregon and dry in California, of which the winters of 1896, 1897, 1898, and 1899 are examples, is evidently due to the building up of high pressure over the Great Basin. When this happens, areas of low pressure pass directly eastward over northern Washington or southern British Columbia, too far north to give rains except to the extreme north coast region of California. The building up of high pressure in the region west of the Rocky Mountains is clearly a result of the general circulation of the atmosphere, although the process may be facilitated by local conditions of snow cover and intensive radiation peculiar to parts of that region.

Dry winters.—It is easy to pass from the foregoing to a consideration of the pressure distribution which attends dry winters. As in the case of wet winters dry winters may be grouped according as the deficiency is general in all three districts or in but a single district. In what follows reference is made to those winters in which the deficiency in precipitation was general in all three districts. These years were 1891–92, 1892–93, 1899–1900, 1902–3, 1903–4, 1905–6, 1911–12, 1912–13, and 1919–20, in all nine winters in which there was a general deficiency in precipitation. The lack of precipitation seems to be clearly due to an intensification of the winter area of high pressure over the Great Basin; in some years this high extends to the westward as far as the coast with the result that areas of low pressure uniformly pass to the eastward north of the Columbia River, and dry weather in California as well as in Washington and Oregon results.

Since the Great Basin HIGH rarely persists so long as a month there must be intermediate periods when rain falls on the coast of Washington and Oregon. In California, however, rain is much less likely because the interval between the breaking down of one Great Basin HIGH and the building up of a second one is too short to permit of the development of areas of low pressure off the California coast. I have shown elsewhere that in the cold months the Great Basin HIGH is periodically renewed through the general circulation and that its semipermanent characteristics are more apparent than real.

The difficulty is establishing definite relations between pressure distribution and precipitation for Pacific Coast States is accentuated by the fact that the available statistics have been compiled for the month as a time unit. Monthly statistics at times but imperfectly reveal the actual conditions which were experienced. It must be kept in mind that only in cases of very pronounced disturbances of the normal conditions which, in the nature of the case are of infrequent occurrence, can the true relations be clearly perceived. An examination of the data as to wet and dry winters as presented in Table 1 shows at once the lack of uniformity in the distribution of precipitation on the Pacific coast and this is not unexpected when one considers that in the temperate zones the dominant weather controls are constantly changing from one extreme to the other. Periods of stable or fair weather and unstable or rainy weather follow one another apparently without rhythm or order; so it happens that months which on the whole are dry may have short periods of abundant rains; space does not permit us to elaborate upon this idea, but a single example may be helpful.

The winter of 1902–3 appears in Table 1 as a season of deficient rainfall in the north and middle Pacific coast regions and of slightly more than the normal rainfall in the south Pacific region. The month of December, 1902, was wet in the north Pacific coast region and dry in California. It was followed by dry weather from January 1 to 19 generally throughout the entire region and from the 19th until the end of the month by a series of rainstorms which had they occurred earlier in the month and continued over a longer time would have changed the aspect of the month considerably; as it was, the total rainfall was slightly above the normal throughout California. This rainy period continued until about February 6 when a series of areas of high pressure moved into the Great Basin region completely dominating the weather in California for the remainder of the month. As we have before observed, high pressure in the Great Basin region is inimical to rain in California. The mean sea-level pressure at Boise, Idaho, for February 1903, was 30.30 inches. Now if we were to consider only the monthly mean pressures for January and February we would be justified in classing both months as dry, but we have seen that in each of them there was a short period of abundant rains.

It is now reasonably certain that the solution of the problem of seasonal rainfall forecasts for California, and in a sense for the States of Washington and Oregon also, lies in the anticipation of those great changes in the physical condition of the atmosphere over a large portion of the earth's surface, which changes in themselves induce other changes in the general circulation of the atmosphere, resulting later in important variations in the rainfall of the western portion of the North American continent.

If it can be foreseen, for example, that the atmosphere of the region occupied by the Aleutian LOW will be of greater density than usual, that the geographic boundaries of this LOW will be greatly restricted in space, then, it is believed the discharge of polar air to lower latitudes will be facilitated and the rainfall of Washington and Oregon will be deficient; if, on the other hand, the reverse conditions obtain we shall probably be justified in predicting abundant rainfall in the Pacific Coast States.

Following out the thought elsewhere expressed, that the key to weather changes is to be sought in variations in atmospheric pressure, I have computed the 12-month consecutive means of pressure for Honolulu, Hawaii, San Diego, Calif., and Salt Lake City, Utah, for 29 years, 1892 to 1920, both inclusive; also for Sitka, Alaska, Jan., 1909–Dec., 1919. Twelve-month consecutive means are obtained as follows: Compute, for example, the arithmetical mean of the 12 calendar months, which in ordinary practice would represent the annual mean. Instead of calling it the annual mean, let us consider it as the mean for the middle point of the period, viz, July 1; then form a new sum by dropping the first term of the original sum and adding that of the 13th month from the origin, dividing by 12, and so on indefinitely. Expressed in mathematical language, $(M_1+M_2+M_3+\ldots\ldots M_{12}\div 12)$; $(M_2+M_3+M_4\ldots\ldots M_{13}\div 12)$ would represent the consecutive or overlapping means in any series where M_1, M_2, and M_3 are consecutive monthly means in the series. Means thus obtained were used in this country by Clayton and later by Aretowski. The advantage they possess is that both the short and the long period varia-

[a] Weather Forecasting in the United States, Weather Bureau, Washington, 1916, p. 132.

tions in the data are readily perceived. Care should be exercised in making comparisons between two places widely separated in order not to confuse that which may be due to the accident of geographic position with results which may be due to changes in the general circulation of the atmosphere.

An examination of these data shows at once that the accidental pressure changes at Honolulu are less frequent and that the amplitude of the oscillations up and down is very much smaller than at the more northerly stations of the North American continent. Plotting the data gives four very instructive curves. It is seen at once that the larger progressive changes at these widely separated places are sometimes in the same sense, at other times in an opposite sense, and at still other times there seems to be little, if any, relation between the curves. A parallel movement in the curves is seen in the maxima of 1893–94 and 1917. In the first named the peak of the maximum was reached at Honolulu in February, at San Diego two months later, and at Salt Lake four months later. From the general course of the curve and the lag in the maximum at the last named, as compared with San Diego, it is suspected that after all there is not a simple progressive motion from west to east, but that the pressure at Salt Lake is conditioned by factors which do not apply to San Diego or Honolulu. The extensive maximum of 1917 first appeared at Sitka in February, at Honolulu in April, at Salt Lake in June, and at San Diego in July. This sequence would seem to indicate a movement fan-shaped to the south and west. The course of the present curve for Sitka seems to negative the idea that pressure at that station varies in the opposite sense to that at Honolulu, although there are times when that is true in part.

The sudden and intense fluctuations in the pressure at Sitka from one month to the next and the general character of the progressive changes must surely militate against the use of the Sitka pressures in seasonal forecasting. It is conceivable that a slight variation in the geographic position of the Aleutian LOW would bring the station Sitka within its influence and, on the other hand, a slight surge of the interior continental HIGH to the westward would bring the station within a region of high pressure. And, moreover, since the interval between the appearance of any certain type of pressure distribution in Alaska and its effect upon the weather in the western part of the United States is, at most, only a day or so, it can be readily seen that seasonal forecasts of weather on the Pacific coast can not be based on Alaskan pressures, unless, indeed, the pressure distribution itself can be forecast.

It has been suggested in some quarters that there is a tendency on the part of the weather to persist, once a type has become well established. This tendency is recognized and made use of by forecasters, but it can never assume importance in seasonal forecasting, simply because thus far no forecaster has been able to anticipate in advance when the type in question would set in, and after it has set in as to just when it would revert to an entirely different type.

I have thought it worth while, however, to compare the December mean station pressures at Salt Lake City, Utah, with the pressures in the immediately following months of January and February. Salt Lake was selected partly on account of its geographic position, being nearly in the center of the Great Basin region, and partly because the record for the period 1892–1920 is complete.

It appears from an examination of the monthly departures that the December departure was followed in the succeeding month of January by departures of the same sign, regardless of the magnitude, in 14 out of the 29 winters examined; in other words there is about an even chance that the pressure departure of January will be of the same sign as that of December. January and February being compared in like manner give precisely the same result, therefore it seems reasonable and probable that whenever the pressure at Salt Lake City or other station in the Great Basin region is below the normal in December there is about an even chance that it will be below in the ensuing month of January, and this condition, i. e., low pressure in the Great Basin region in winter is favorable to abundant precipitation in California in the corresponding months. The converse, high pressure in the Great Basin region is inimical to precipitation in California. It is interesting to note that the winters of heavy precipitation in California, 1895–96, 1906–7, 1908–9, 1913–14, 1914–15, and 1915–16 were, with but one exception, winters of diminished pressure in December at Salt Lake City. It must not be understood that these two events, low pressure in the Great Basin and increased precipitation in California, stand in the relation of cause and effect, but rather that the low pressure in the Great Basin is part and parcel of a much more extensive change in the pressure distribution that is directly concerned with the occurrence of precipitation in Pacific Coast States.

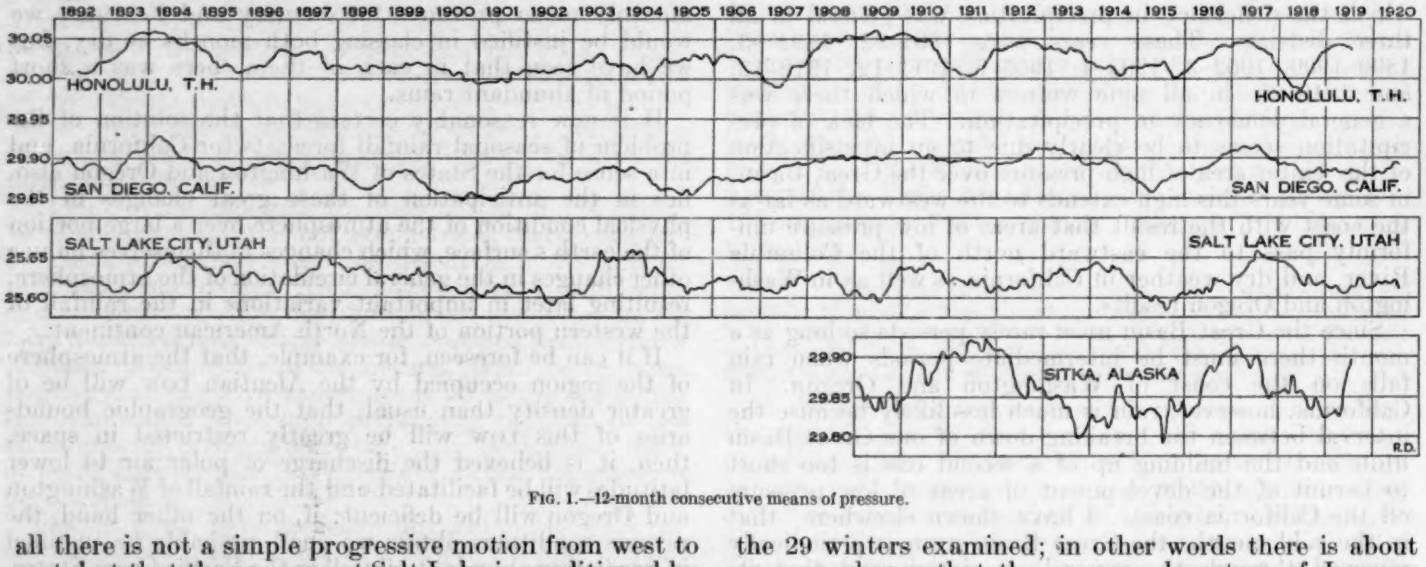


Fig. 1.—12-month consecutive means of pressure.

For comparison with the data of Table 1, rainfall departures, I give in the subjoined table the station pressure departures for the winter months at Salt Lake City.

TABLE 2.—*Departure from the normal of station pressures at Salt Lake City, Utah, winter months only.*

[In thousandths of an inch.]

Years.	December.	January.	February.	Years.	December.	January.	February.
1891–92	0.077	**0.042**	0.023	1906–7	0.024	0.102	**0.061**
1892–93	.025	**.048**	.002	1907–8	.048	**.036**	.011
1893–94	**.041**	.025	**.034**	1908–9	.010	.127	.073
1894–95	.024	.122	**.075**	1909–10	.056	**.012**	**.021**
1895–96	**.028**	.014	**.081**	1910–11	**.031**	.038	.045
1896–97	**.048**	**.014**	.073	1911–12	.064	**.008**	**.032**
1897–98	**.062**	**.004**	**.084**	1912–13	**.038**	**.017**	**.069**
1898–99	**.112**	.001	.024	1913–14	.007	.065	**.057**
1899–1900	**.063**	.072	.000	1914–15	.069	.057	.071
1900–1	**.073**	.002	.020	1915–16	.064	.204	**.085**
1901–2	**.033**	**.024**	.048	1916–17	.136	**.010**	**.031**
1902–3	.029	.002	**.037**	1917–18	**.018**	.064	.005
1903–4	**.114**	**.296**	.078	1918–19	.030	**.104**	.125
1904–5	.005	**.044**	**.003**	1919–20	**.052**	**.084**	**.037**
1905–6	**.063**	**.036**	**.023**	1920–21	.092		

Negative departures in ordinary type; positive in full-faced type.

CONCLUSIONS.

The effort has been made in the foregoing analysis to discover from the available observational material, which is confessedly inadequate, the true nature of the weather phenomena associated with years of heavy and years of light precipitation on the Pacific coast. This effort has been aided and supplemented by the personal experience of the writer in weather forecasting from synoptic charts and his contact for many years with the daily weather maps of the United States and Canada. The most valuable asset that one can bring to the study of the problem is that of experience in forecasting the day-to-day weather. There are several fundamental facts which can not be so readily grasped in any other way. These are: (1) The general instability of cyclonic and anticyclonic systems; that is to say there is little, or no assurance, that, for example, when a cyclonic system enters the continent from the Pacific it will endure for any specified time; that its motion will continue in the original direction or be in a different course and finally whether its original speed will remain constant, increase or diminish. (2) That, so far as the forecaster can perceive this general instability is conditioned upon the pressure, temperature, and moisture-content of the atmosphere at the moment, not only in the immediate field of observation but also in distant regions. (3) That, while the distribution of heat undoubtedly sets in motion a series of movements in the atmosphere which result in the origin of cyclones and anticyclones, yet the controlling factor or factors which set in motion, maintain, and change the nature of these phenomena have not yet been recognized with sufficient definiteness to be useful to the day-to-day forecaster. The conclusion is therefore irresistible that the explanation of variations in the weather of the United States and other regions in the same latitude is to be found in a study of the general problem of atmospheric circulation, particularly as to those influences which control or modify the slow interchange of air between the equator and the poles. This interchange I believe is largely brought about by the development and movement of cyclones and anticyclones which as is well known differs from season to season. The problem therefore is first to attempt to predict the temperature, the moisture content and the movement of the atmosphere over that portion of the globe embraced between the 90th and 180th meridians of west longitude and 20° to 60° of north latitude. Local conditions as to temperature, whether of land or water, in parts of this area are seemingly inadequate to account for the great changes in the air currents which are associated with variations in precipitation.

The futility of attempts to show a relation between the changing spottedness of the sun and terrestrial weather becomes more and more apparent as one seriously examines the terrestrial data in connection with weather extremes of whatsoever character. While it is not yet possible to forecast in advance the rainfall for a season by a rational deductive process, I may at least point out the line of action which might lead to the accomplishment of that object.

The greatest need at the present time is for observation from the Pacific which will enable one to delimit the area of high pressure the center of which normally in October, let us say, is found about latitude 30° north and longitude 140° west. At the same time, our knowledge of the intensity and geographic extent of the Aleutian LOW should be extended and this can be done best through ships navigating the waters of the Pacific to the southwest of the westernmost part of the Aleutian chain. By charting these observations day by day for at least 25 years, sufficient knowledge will be available to at least discuss the problem intelligently.

It is assumed of course that 25 years' additional observations from Honolulu, Midway Island, and Alaska will also be available.

NOTE ADDED MARCH 26, 1921.

In a discussion with officials of the Weather Bureau staff after the completion of this paper, it was brought to my attention that in 1898 it was suggested on the evidence afforded by three years' temperature observations at Dutch Harbor, Alaska, that high temperature in the Aleutian group is followed three months later by increased precipitation in California. The proponent of the proposition was well aware of the fact that the short temperature record then available afforded but slight grounds for the belief that the relation was real. Subsequent discussion, particularly that of Mr. Alexander McC. Ashley of the Central Office of the Weather Bureau, in January, 1901,[1] showed that the favorable evidence of the short temperature record was probably merely a coincidence, and should not be considered as indicating the existence of a real connection.

However, since any observational material within the region of the semipermanent Aleutian LOW must be helpful to a better understanding of the phenomena of the weather in that region, I have thought it advisable to consider the original proposition de novo, in the light of more abundant temperature observations which are now available. I have therefore consolidated the two chief series of temperature observations, the one at Dutch Harbor, Alaska, which was begun by the United States Signal Service in 1882, and resumed by the Weather Bureau in 1905; the other a cooperative record made on Unga Island, Alaska, about 240 miles east of Dutch Harbor, begun in 1886 and ended in 1910, although the last year has been rejected. There were, however, aside from

[1] Long Range Seasonal Forecasts for the Pacific Coast States, Alexander McC. Ashley MON. WEATHER REV., 29: 16.

that year, nearly four years' observations made concurrently with those at Dutch Harbor, from which it has been possible to deduce a series of monthly corrections to reduce the Unga Island record to that of Dutch Harbor. Consolidating the two records after applying a constant correction to the monthly means of Unga Island, I get the nearly continuous record presented in Table 3, next following:

TABLE 3.—*Monthly mean temperature at Dutch Harbor, Unalaska Island, Alaska.* [F.]

[Latitude, 53° 54′ N.; longitude, 166° 32′ W.; elevation, 30 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1882	36.5	31.4	34.4	37.2	42.6	46.6	51.3	52.2	47.9	43.8	37.0	27.8
1883	34.5	31.2	30.6	32.6	40.1	45.9	49.9	50.4	46.0	43.4	36.3	30.6
1884	33.6	36.5	38.7	36.5	39.2	45.7	50.8	50.3	48.1	40.6	36.8	35.0
1885	37.2	27.4	31.7	36.6	41.7	45.2	48.8	50.3	45.1	41.5	35.5	33.9
1886	33.6	27.9	32.2	36.1	42.3	......	54.6	54.0	48.9	39.8	30.2	26.3
1887	28.8	32.5	29.4	36.6	37.7	48.4	49.6	51.0	47.9	39.8	31.2	28.3
1888	38.8	34.5	40.4	34.6	43.7	49.4	49.6	58.0	47.9	41.8	29.2	31.5
1889	38.8	27.0	35.4	35.6	36.7	47.2	48.8	50.4	38.9	37.8	32.2	32.3
1890	31.6	28.6	31.7	33.0	38.9	43.5	49.4	53.1	46.9	......	......	......
1891	......	......	......	......	......	......	......	55.5	49.8	41.6	36.3	21.4
1892	29.0	25.7	25.4	37.4	43.0	51.3	52.8	53.9	46.3	38.5	35.1	33.7
1893	29.7	33.6	34.7	37.5	39.6	48.1	49.3	49.6	48.7	39.2	34.8	32.7
1894	27.7	22.9	29.9	32.6	33.6	43.9	51.1	50.8	47.2	37.6	32.7	27.7
1895	27.1	30.6	30.7	30.4	38.4	45.8	48.4	50.4	46.5	40.3	36.6	26.4
1896	23.1	20.5	34.0	34.2	37.1	45.6	48.8	50.3	46.7	40.2	37.1	29.6
1897	34.0	35.4	29.7	39.0	42.3	46.0	49.8	53.1	48.1	38.8	38.3	35.7
1898	34.0	25.3	38.6	39.1	39.4	44.7	50.8	49.6	46.7	39.8	35.2	30.5
1899	29.2	33.5	37.1	38.4	38.2	48.0	52.6	51.6	47.7	42.4	35.6	28.3
1900	30.9	36.5	35.8	34.8	39.3	48.9	49.1	53.2	48.3	42.2	35.8	......
1901	34.0	30.8	30.0	34.5	37.5	44.7	49.5	51.2	46.8	39.6	32.2	32.4
1902	34.0	35.5	34.2	35.6	41.1	52.0	53.5	51.5	47.6	......	......	......
1903	26.0	31.1	37.4	36.1	39.3	46.2	47.8	50.6	47.0	36.3	29.8	32.2
1904	29.0	28.3	32.4	33.8	38.7	44.3	47.9	48.8	48.3	39.4	30.8	25.7
1905	34.2	34.7	35.2	41.2	41.5	47.0	52.3	52.7	46.1	41.5	37.4	30.5
1906	26.6	33.4	31.9	35.2	39.0	44.0	48.4	49.8	48.7	41.4	35.2	35.1
1907	37.6	26.4	37.2	33.1	39.4	47.1	......	......	......	40.0	34.2	30.0
1908	28.2	32.4	30.3	30.0	38.1	45.6	48.4	50.3	46.9	41.5	33.8	34.8
1909	31.8	34.1	30.0	37.0	39.6	46.0	52.1	52.7	44.0	40.4	36.6	30.6
1910	31.8	33.2	28.0	30.4	42.2	47.8	57.6	......	49.5	41.4	33.8	......
1911	33.8	34.8	34.6	36.6	40.8	......	54.2	55.4	48.8	41.7	36.0	31.9
1912	31.7	33.0	35.2	37.8	39.8	44.9	49.8	50.2	46.6	40.6	34.8	29.0
1913	32.6	35.7	37.0	35.7	39.9	47.0	50.0	50.8	46.5	40.8	36.2	29.6
1914	30.4	36.4	34.4	38.0	42.8	46.2	53.9	53.0	51.3	41.8	37.0	36.5
1915	29.6	30.5	34.0	35.7	43.3	49.2	52.6	50.8	49.4	42.4	36.8	32.6
1916	35.4	29.4	27.5	33.2	37.4	42.2	48.0	49.3	46.8	42.8	34.4	30.8
1917	28.8	34.2	33.5	33.4	40.8	46.4	53.6	50.8	47.9	42.2	29.4	32.8
1918	30.8	31.8	34.6	36.4	43.0	45.4	51.4	51.0	45.4	40.5	32.6	31.5
1919	23.3	29.0	35.1	32.3	38.6	45.8	50.8	49.8	49.2	42.6	35.8	34.4
Means.	31.6	31.2	33.7	35.6	39.9	46.5	50.8	51.6	47.3	40.7	34.2	30.4

This series affords dependable monthly means for about 37 years, and, in a limited sense, may be considered as reflecting the water temperatures of the north Pacific, in the region of the Aleutians, for those years. I have computed the departures for the months August to December, both inclusive, for comparison with the monthly precipitation departures of the middle Pacific coast region—mainly northern and central California—for the months November to March, inclusive.

Comparisons have been made by means of graphs, and I have also made a dot chart (fig. 2), plotting August departures of Aleutian temperatures against departures in California precipitation in November; also September Aleutian temperatures against December precipitation in California. It is evident from the scatter of the dots that there is no orderly relation between the two events. Graphs yield the same result; and moreover, Mr. R. H. Weightman, of the Central Office, in an unpublished manuscript, has reached identical conclusions.

In this connection, I have reread Prof. McAdie's article in the April, 1908, MONTHLY WEATHER REVIEW (p. 99), in which he deduces two general laws for forecasting on the Pacific coast, viz:

A. When the continental HIGH overlies Oregon, Idaho, Utah, and Nevada, the general drift of the surface air is from the north or northeast, and such a cirulation favors fair weather with little precipitation. * * *. Individual LOWS are restricted to northern counties and pass eastward without extending southward.

B. When the north Pacific low area (the Aleutian LOW) extends well southward along the Oregon coast and the continental HIGH overlies Assiniboia [now Saskatchewan] and Montana, the general drift of the surface air in California is from the south or southeast. Conditions (then) favor unsettled weather, with frequent heavy rains west of the Sierra and heavy snowfall in the Sierra. Individual HIGHS appear with little warning north and east of the Kootenai, and move, as a rule, slowly south. Individual LOWS appearing over Vancouver Island and the north coast of Washington deepen and also extend southward, the rain-area reaching northern California in 12 hours, the central coast in 24 hours, and the coast south of Point Conception in 36 hours.

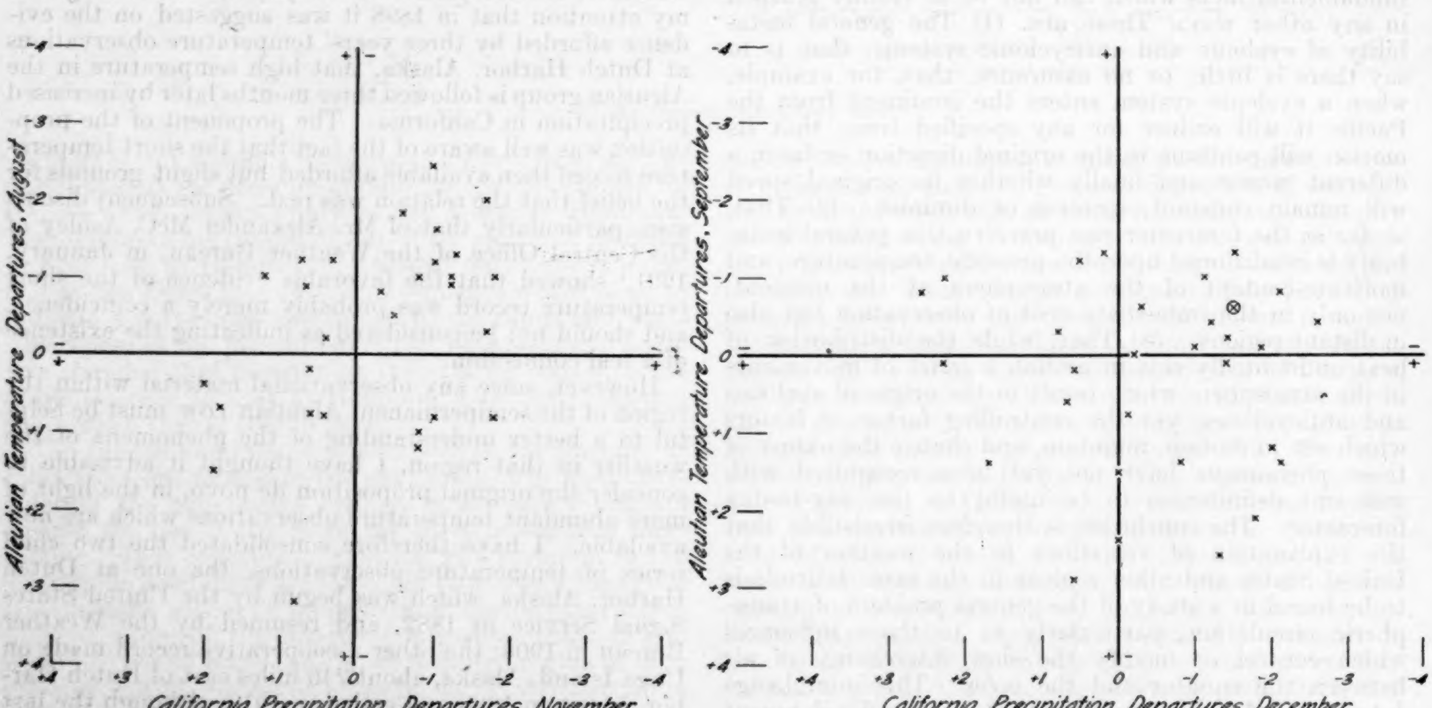


FIG 2.—On left, Aleutian temperature departures of August and precipitation departures in California, three months later; on right, the same, but for September temperatures and December precipitation.

The above statement of the general principles which obtain in forecasting for the Pacific coast, are in close accord with the conception of the problem as presented in this paper.

RECORD-BREAKING RAINFALL IN JAMAICA IN JANUARY, FEBRUARY, AND MARCH, 1921.

(Excerpts from *Jamaica Weather Report*, Feb. and Mar., 1921, p. 4.)

The mean rainfall for the entire Island during February was somewhat over twice the normal. Moore Town, in Portland Parish, had a total fall of 27.73 inches during the month, while at Belvedere, in the same parish, there was a 24-hour fall of 9.05 inches. The average precipitation for the Island was 7.22 inches—the greatest amount for any February in 50 years. It is worth noting that the average rainfall for January of this year was 10.87 inches, being the greatest of any January on record. The rainfall for March was 84 per cent above normal.—*H. L.*

APPLIED CLIMATOLOGY IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau Office, San Francisco, Calif., May 17, 1921.]

SYNOPSIS.

The work done at a climatological section center of the Weather Bureau furnishes good evidence of the many and varied applications of climatology. These are not known to the general public, and even professional meteorologists have but a limited appreciation of their extent and variety. The practical applications of climatology in California are here briefly enumerated and described in the hope that the survey may be of interest and perhaps of value in other climatological sections, and with a desire that it may inspire similar surveys of other regions. In California the Weather Bureau acts as a meteorological and climatological center of information and clearing house, and supervises the gathering and publication of a small fraction of the data available. Municipalities, industries, public service corporations, business houses, resorts and institutions maintain climatological stations and secure data which are of great practical value in agriculture, manufacture, industry, mining, transportation, aviation, conservation, public service, advertising, public health and recreation.

INTRODUCTION.

Because of its vast size, its wide range of latitude, its uneven topography and the contrasts of climate which result therefrom, California presents great variety in the uses and applications of climatology, a variety which is probably not equaled by any other State. The following is a brief survey of applied climatology in California, a field which is so extensive that only the salient features can be here referred to.

WEATHER BUREAU ACTIVITIES.

Practically all of the meteorological and climatological activities of the United States Government in California are conducted by the Weather Bureau. While this is the largest single organization engaged in the task of accumulating meteorological and climatological data and making the same available for public use, its activities represent only a small fraction of the total work of this kind carried on in this State. The Weather Bureau serves as a meteorological and climatological clearing house. But the demands for detailed data are so extensive, and these demands are increasing so rapidly that the limited appropriations allowed the Weather Bureau do not permit it to render as complete service as might be rendered with more liberal appropriations.

Briefly stated, the Weather Bureau maintains 11 regular first-class stations, situated at the following places: San Francisco, Los Angeles, Sacramento, Fresno, San Diego, Eureka, Red Bluff, San Jose, San Luis Obispo, Independence, and Point Reyes. The first named is the district forecast center and the climatological section center. Special attention is paid to river and flood data at Sacramento, Fresno, and Eureka. Marine vessel movements are reported at Point Reyes. Storm warning stations are located at eight prominent points along the coast. In addition, approximately 300 climatological substations are maintained, but the observers at only about 10 per cent of these receive nominal compensation (because of special observations and service required), the others being volunteer and unpaid cooperative observers. At all stations special attention is paid to precipitation data, since precipitation is the most important element of climate in California. The Weather Bureau has the cordial cooperation of all the various agencies engaged in gathering weather data, but the extent of the cooperation varies, since the Bureau is unable to supervise the gathering and the publication of more than a small fraction of the data available.

MUNICIPAL CLIMATOLOGY.

The municipal governments of two cities, Oakland and Santa Barbara, have installed the complete meteorological equipment of a first-class Weather Bureau station, including the triple register. In Oakland the apparatus forms part of the equipment of Chabot Observatory, a suburban observatory which is maintained under the auspices of the board of education and is open to public inspection during certain hours. It is a combined meteorological and astronomical observatory, ideally and permanently located on a large tract of land at the edge of the city. At Santa Barbara the municipality has installed complete meteorological apparatus on the grounds surrounding the home of one of its prominent residents. More than $1,000 has been expended in standard equipment with the hope that the Weather Bureau may eventually take over the same and maintain a first-class station at this place.

The city of San Francisco is at present building an aqueduct which will eventually bring water to the city from the Hetch Hetchy Valley, almost 200 miles distant. Since climate and particularly precipitation is an important factor in construction, water supply and hydroelectric power, the municipality maintains two weather stations in the drainage basin, namely, at Hetch Hetchy and Lake Eleanor.

Likewise, the city of Los Angeles, whose aqueduct is complete and in operation, maintains several climatological stations along its route, notably at Fairmont and in the Owens Valley.

The city of San Diego also maintains such a station at Barrett Dam, a link in its water supply system.

The city of Vallejo, the municipality adjoining the United States Navy Yard at Mare Island, has recently installed 36 standard 8-inch rain gages in an elevated valley which it proposes to use as a drainage basin for its future water supply, if the precipitation there comes up to expectations.

A number of communities maintain climatological stations under the supervision of a city official, usually

the city clerk or the city engineer. Among such cities are Pasadena, Santa Cruz, Livermore, Oceanside, Placerville, and Santa Maria.

In connection with flood-control and water-supply investigations, an intensive survey of precipitation in southern California is being conducted on the basis of data secured at a large number of special rainfall stations in the immediate vicinity of Los Angeles. This investigation was provided for by an agreement made between the Honorable Secretary of Agriculture and the Board of Supervisors of Los Angeles County. It is expected to continue for 10 years or more.

CLIMATOLOGY AT EDUCATIONAL INSTITUTIONS.

Partly for the purpose of securing needed data and partly for educational purposes, various educational and research institutions maintain climatological stations. The University of California maintains four such stations, besides two evaporation stations. At the observatory on the main campus of the University in Berkeley a climatological station is maintained under the auspices of the Department of Geography. Another station is maintained at Lick Observatory, on the summit of Mount Hamilton, altitude 4,209 feet, this institution being a part of the university's Department of Astronomy. A feature of the equipment at this station is the use of a considerable number of self-registering meteorological instruments, which are of particular interest to visitors. The observatory is open to the public daily, and occasionally during evening hours. Another station is maintained at Davis, the seat of the agricultural division of the university, where the instruments are attended to by the Department of Irrigation Investigations. A fourth station is maintained by the university's Department of Forestry near Santa Monica, at a forest experiment station.

The Carnegie Institution of Washington, at its solar observatory on the summit of Mount Wilson, altitude 5,704 feet, maintains a first-class station. Data from this elevated station are of considerable value in weather forecasting for southern California, as well as in the study of water resources. The data are also used to aid aviation, which is rapidly growing in importance in California.

A completely equipped, first-class meteorological station is maintained by the University of Santa Clara, in the valley of the same name, and about 3 miles distant from San Jose. The equipment of the observatory also includes astronomical instruments and a seismograph. The director is Rev. J. S. Ricard, S. J., who has long been a student of long-range weather forecasting as based on sunspots.

Pomona College, in southern California, also maintains a climatological station. The data are used for educational purposes, and also in fruit-frost investigations, as the station is in the heart of extensive orange and lemon groves. The science department of Lakeport High School maintains a station at the home of one of its instructors. Another station is maintained at Raja Yoga Academy, of the Theosophical Institution, on Point Loma, a prominent headland at the entrance to San Diego Bay. The station is maintained under the supervision of Prof. F. J. Dick, who has designed and constructed a novel seismograph, which forms part of the observatory equipment.

AGRICULTURAL CLIMATOLOGY.

While most climatological data obtained in California are used directly or indirectly in agriculture, certain stations are maintained primarily for this purpose. The variety of applications in scientific agriculture is extensive, as is apparent from the following:

The Spreckels Sugar Co. maintains an experiment station at the headquarters of the company in the town of Spreckels, near Salinas, in Monterey County. Near the mammoth sugar refinery there has been erected a modern scientific laboratory, which includes in its equipment all the standard meteorological instruments found at a first-class Weather Bureau station, including a triple register, evaporation pan, and air and soil thermometers of various kinds. Sugar beets alone form the source of supply of the sugar manufactured here. Investigations have shown that there is an intimate and complex relationship between weather and the sugar content of beets. The optimum weather condition has never been determined exactly, as it varies with soil, elevation, latitude, and time of planting. Moreover, it has been recognized that the optimum weather for the production of sugar in beets is not the best weather for the production of seed. As a result of these conclusions, the experiment station has established a considerable number of climatological stations in the extensive sugar-beet fields near the coast of central California and in the interior valleys. Another company, the Union Sugar Co., with headquarters at Betteravia, also maintains a climatological service of its own, but on a less extensive scale.

In the field of horticulture citrus fruit receives more attention than any other crop. Owing to the sensitive character of citrus-fruit trees, and because of the fact that certain kinds of citrus fruit, notably lemons, mature on the same tree throughout the year, climate naturally determines the districts available for successful culture. The bulk of the crop is grown in southern California, largely because of the absence there of severe or prolonged cold. However, the foothills of the interior valleys of central and northern California have been found to be well adapted for citrus-fruit culture, and the acreage is increasing from year to year. Because of the greater amount of sunshine received, the most northerly orange groves, those near Oroville, invariably produce the first mature oranges every autumn. Fancy prices are received for such fruit when offered in eastern markets during the Thanksgiving and Christmas demand. It is perhaps unnecessary to add that climatological data form an important consideration in the successful production of citrus fruit. The application of such data relates principally to frost, orchard heating, smudging, irrigation, sunshine, hot waves, fumigation, "June drop," insect pests, and favorable harvesting and storage conditions. Nearly all the large citrus-growing regions have climatological stations, and the instruments are usually situated in or near fruit groves. On the official weather maps issued at certain Weather Bureau stations and in data published by the daily press observations appear under the heading, "Orchard Temperatures." Among the most prominent orchard climatological stations are Pomona, Redlands, Riverside, Porterville, Lemon Cove, Lindsay, Oroville, and Yorba Linda.

Successful date culture on a commercial scale requires tropical or semitropical weather conditions. Frosts or prolonged low temperatures can not be endured by the date palm, and the mean temperature of the air must be relatively high. On the other hand, the water requirements are light, and the palms will flourish in what appears to be a sandy desert, provided that the temperature conditions are favorable. These peculiar conditions are found in the Coachella Valley, where the United States Bureau of Plant Industry has introduced the culture of the date palm on an extensive scale. About 70 different

species are now under experimental cultivation at the Indio experiment station. Most of the seedlings were originally imported from Africa or from southern Asia. Seedlings of the varieties best adapted to California conditions are already available for distribution. One of these varieties, "Delget Noor," has been found to be adapted for general cultivation in the Imperial Valley, that great "inland empire" destined some day to be a vast agricultural region, but as yet comparatively undeveloped. Climatology has contributed in no small measure to the successful introduction of the date palm. Meteorological instruments form an important part of the equipment of the Indio experiment station and of the Mecca substation.

Death Valley is of scientific interest because here the highest natural shade temperature ever recorded with a standard thermometer, namely, 134°, occurred on July 10, 1913. Nearly every year the highest temperature officially recorded in the United States occurs here. This valley, which is mostly below sea level, is about 50 miles long and 400 feet to 8 miles wide, and lies between precipitous mountain ranges. It contains but one permanent human habitation. The latter is known as Greenland Ranch, because the green appearance of the alfalfa, grown under irrigation there, is in marked contrast with the brown desert surrounding. In the pioneer days the ranch was known as Furnace Creek Ranch, also an appropriate name because of the unbearable heat during summer months. The ranch is owned and maintained by the Pacific Coast Borax Co. as a source of food supply for the miners employed in the mountains nearby. The foreman of the ranch acts as cooperative observer for the Weather Bureau, and the climatological station is a feature of the equipment of this unique and isolated community. The rain-gage is not often used, as a whole year sometimes goes by without measurable precipitation.

Less than 10 years ago the United States Department of Agriculture introduced rice culture into California on a commercial scale in the flood plain of the Sacramento River. This land, worthless for most ordinary purposes, was found to be well adapted for rice growing. The new industry grew rapidly, and recent harvests have been valued at many millions of dollars. The limiting factor seems to be inadequate water supply to satisfy the high water requirements of rice. Because of drought and the large use of water by rice growers the Sacramento River above the city of Sacramento was almost pumped dry during the summer of 1920. Climatology again contributed essential data in the introduction and development of the industry. Of particular importance are precipitation and river-stage data in connection with the irrigation of the rice fields. At Dodgeland, in the heart of the rice-growing district, the Weather Bureau maintains an evaporation station in cooperation with the Dodge Land Co., one of the largest interests in the valley. The University of California also maintains an independent evaporation station in the valley in connection with its rice experiment station. The same institution maintains another evaporation station in the Imperial Valley, where cotton culture has been introduced on a commercial scale. The experiments with cotton have resulted in the production of a high-grade, long-staple cotton, which commands a premium in price because of its advantages in the manufacture of automobile tires. Recently cotton culture has been introduced into the San Joaquin Valley with conspicuous success.

An experiment station maintained by the United States Bureau of Plant Industry at Chico has been used mainly as a plant introduction garden. Here imported species of trees, shrubs, and plants are tested before general distribution is made. Climate is an important consideration in these experiments, and the climatological data gathered here form an essential part of nearly every report. Of popular interest at present is the attempt to introduce the bamboo to the agriculture of the United States. Of the several species under culture it is hoped that at least one will be found adapted to production on a commercial scale.

The United States Reclamation Service maintains an experiment station at Orland, and here also climatological data are an important consideration. This is the administrative center of the Orland project, where reclamation on an extensive scale has made possible "the growing of two blades of grass where but one grew before."

A climatological survey is at present being conducted on a large tract of land owned by Mr. William Randolph Hearst, and situated in the vicinity of San Simeon. This tract, at present uncultivated, will be surveyed with the object of determining which kinds of agriculture will be best adapted for the different portions of the tract. A number of standard climatological stations have been established at strategic points on the tract. The survey is being made by the San Francisco engineering firm of Thomas Means.

A similar tract, partly under cultivation and partly devoted to grazing, is situated a few miles south of Bakersfield at the extreme southern end of the San Joaquin Valley. A climatological station is maintained as a part of the headquarters equipment.

The Grangers' Union, an association of ranchers in San Benito County, also maintains a climatological station at headquarters in Hollister.

INDUSTRIAL CLIMATOLOGY.

The largest single industry which keeps systematic climatological records is the Southern Pacific Co. Approximately 250 Southern Pacific Railway station agents keep temperature and precipitation records. The thermometer employed usually consists of an ordinary mercury thermometer, and at most stations it is simply nailed to the side of the railroad station building without an inclosing shelter of any kind. The instrument is read three times a day. The rain-gage used is but 3 inches in diameter. Monthly reports are forwarded to the company's headquarters in San Francisco. The data are used by the engineering and freight-claim departments, but as the data are obtained from instruments which are not recognized as standard, they are of little value for comparative purposes.

The development of hydroelectricity is one of the leading industries in California to-day. Because of the absence of coal deposits and the rapidly vanishing oil supply, hydroelectricity is destined to become increasingly important. For obvious reasons, hydroelectric power companies are much interested in climatological data, especially precipitation and evaporation. Climatological records are kept at nearly every hydroelectric generating station and at most reservoirs. Moreover, records are kept at many of the dams to determine the loss of stored water through evaporation. Most of the instrumental equipment used by the power companies is

standard. As the rain-gage is invariably an 8-inch standard, the precipitation data are comparable with those of hundreds of other rainfall stations. The power companies are naturally interested in the snowfall at high altitudes, since packed snow is really stored water which will become available upon melting. The management secures needed information from regular daily observations and from periodical snow surveys. Such snow surveys are also made by the Weather Bureau, by the State engineer, and by Prof. J. E. Church, jr., of the University of Nevada. Private, State, and Federal observers cooperate in this work. Cooperative stations of the Weather Bureau are situated at 15 power houses or reservoirs.

Mining companies are also dependent more or less upon climatic conditions, particularly with reference to precipitation, stream flow, and hydroelectricity. Cooperative stations of the Weather Bureau are situated at four gold mines, Grass Valley, Bishop Creek, Helen Mine, and Kennedy Mine, and at one quicksilver mine, Idria. The American Trona Corporation has recently erected a large plant on the site of an old lake bed in San Bernardino County, in the midst of the desert. Potash, borax, and other chemicals are extracted from the brine and residual deposits of the vanishing lake. The complete equipment of a first-class meteorological station is in operation here, including a triple register and an evaporation pan. The United States Smelting, Refining & Mining Co. operates a number of copper mines in extreme northern California. Fumes from a large smelter at Kennett are claimed to have influenced unfavorably the agriculture of a large territory surrounding, and much litigation has resulted. In order to secure climatological data needed in contesting these claims the company has installed complete first-class meteorological stations at Kennett and Redding. In addition, a service which includes about a dozen substations is maintained, each of the latter stations being equipped with thermometers, shelter, rain-gage, and wind vane. (It is of interest to note in passing that when the company established the latter service it was unable to purchase an inexpensive wind vane in the market, as there are apparently none on sale, so the instruments had to be made to order.)

The extraction of salt from sea water is an important industry in the San Francisco and San Diego Bay regions. Since temperature, sunshine, precipitation and evaporation are important factors in the evaporation of the brine, most of the plants are equipped with meteorological instruments. The Weather Bureau maintains a standard evaporation station at the Chula Vista plant of the Western Salt Co. near San Diego.

The transportation of oil through pipe lines is an important industry which is also dependent upon climatological conditions. There are hundreds of miles of such pipe lines in California through which the crude oil is pumped from the oil fields to the refineries. The latter are situated along the coast, and convert the crude oil into various petroleum products, particularly gasoline. It has been found that temperature plays an important part in the economy of oil transportation by pipe line. For this reason may of the pumping plants have been equiped with thermometers. The Weather Bureau maintains cooperative stations at four oil pumping plants, namely, Dudley, Maricopa, Middlewater and Coalinga.

At Crockett, on San Francisco Bay, is situated one of the world's largest refineries for the manufacture of cane sugar. The crude brown product of Hawaiian sugar cane is brought by steamer to this plant for refining. Many elements influence the process of sugar refining as practiced here, and the meteorological elements are among the most important. There are more than 60 instruments of various kinds in constant use, and a trained assistant devotes his whole and undivided attention to these. The meteorological elements of special significance are temperature, pressure, relative humidity and vapor pressure. To a less extent similar data are kept at beet-sugar refineries at Spreckels and Betteravia.

The production of silk through the culture of silk worms is an infant industry in the United States. The Seriterre Co. is experimenting with the culture of silk worms and the growing of mulberry trees at Seriterre, near Oroville. Thus far the success of the venture has exceeded early expectations. Whereas in foreign countries the culture of silk worms has been limited to air-temperature extremes of 63° F. and 85° F., at Seriterre the culture has been carried successfully through temperature extremes of 48° F. and 107° F. Mr. Guy Wilkinson, one of the prime movers in the venture, has expressed the opinion that the success is due to the stable absolute humidity and absence of marked changes in temperature from day to day. A privately equipped meteorological station is in operation here. There appears to be no good reason why California can not produce silk on a large scale.

Many business houses have found that it is to their own and their customers' interests to keep climatological records. The Marysville Water Co. has erected a meteorological kiosk in the center of a city park. The McCloud River Lumber Co. maintains a climatological station in a private park, the precipitation data being of special value in connection with winter logging operations. General stores in Newman and Cedarville also maintain climatological stations. The First National Bank of Turlock has recently established a similar station. Petaluma has become the most important poultry and egg producing center in northern California largely because of the prominence given by the Chamber of Commerce to the fact that the climate of the region is ideally adapted for poultry. Experimental attempts to convert solar radiation into mechanical energy by means of sunshine engines are being carried on in the desert portions of southeastern California, a part of the region of greatest sunshine in the United States.

At Planada a development company has erected and maintained a first-class meteorological station, including a triple register. In many other towns climatological records are kept by holding corporations, boards of trade, and chambers of commerce.

The development of water resources and the distribution of water for irrigation and for domestic use is intimately related to precipitation and evaporation Climatological records are kept by nearly every water company and irrigation district.

Over 150 airplanes are in use in California to-day, and the demand for aerological data is growing. Transcontinental air mail arrives at and departs from San Francisco daily. The Los Angeles Chamber of Commerce has a separate Department of Aeronautics and Meteorology. Besides the balloon school at Arcadia and the aviation school at North Island, in San Diego Bay, there are numerous flying schools. Commercial aviation companies maintain services available for sightseeing, advertising, and speedy travel. During the summer dry-season the United States Forest Service

maintains an aeroplane forest fire patrol. The Weather Bureau offices at San Francisco and Los Angeles disburse special information daily for the benefit of aviators. Aviation is possible throughout the year.

Newspaper offices are centers of public information in many small towns. Climatological stations are maintained by newspapers at Antioch, Brawley, Redlands, Fort Bidwell, and St. Helena.

CLIMATOLOGY OF RECREATION AND HEALTH.

The national forests and national parks of California are great playgrounds which offer recreation and health facilities to large numbers of persons every year. The United States Forest Service cordially cooperates with the Weather Bureau in securing climatological data which are of interest in recreation, as well as in connection with water supply, grazing, conservation, and protection from forest fires. Some of the climatological stations maintained by the Forest Service are supplied with anemometers in addition to the usual equipment of a cooperative station.

Climatological records are also kept at Glacier Point and at the superintendent's headquarters in the Yosemite National Park; also at Giant Forest in the Sequoia National Park. Various tourist hotels like Del Monte and Squirrel Inn find it good business policy to maintain a climatological record for use in advertising. Records are kept for the same reason at Venice, a beach resort, and at Avalon, an island resort. Many sanitariums in southern California keep climatological records in connection with the scientific treatment of patients. The United States Public Health Service hospital at Arrowhead Springs and the State hospitals at Napa and Stockton also maintain climatological stations for the same purpose. At the State penitentiary at Folsom detailed climatological records are kept at the headquarters of the warden.

From the standpoint of personal comfort and human health the significant features of California climates are light precipitation in most regions, the division of the year into wet and dry seasons, abundant sunshine throughout the year, absence of extreme temperatures, mild winters, and extreme dryness in the southern portion. The latter region is especially suited for convalescents. The entire coast of California serves both as a winter and a summer resort.

PRACTICAL CLIMATOLOGY.

In addition to the practical applications of climatology noted above, there are numerous features which can be enumerated but briefly here. It has been remarked that "we do not have weather in California, we have climate." To a large extent the statement is true. Moreover, in this State water is wealth, and "irrigation water is the lifeblood of the State." Furthermore, future development appears to be dependent upon hydroelectricity, a field of activity which still offers opportunities. A leading San Francisco newspaper recently stated editorially that the greatest problem facing California for the next 10 years is the conservation and use of every drop of rain which falls in the State.

The concentration of the manufacture of motion pictures in southern California is really a result of a favorable climate which makes it possible to work out of doors in comfort nearly every day of the year. California is also the greatest producer of seeds, primarily because climatic conditions favor the production and the harvesting of many varieties of vegetable and flower seeds. The coast region is well adapted for the wholesale production of beans, since the persistent summer fogs furnish sufficient moisture during the rainless season. Bulbs are now being grown on the northern coast because of cool, moist, and frostless climatic conditions. Olives are grown successfully on a commercial scale in the foothills, where frosts are infrequent.

Other miscellaneous facts follow. The determination of water rights is of such magnitude and importance that a State commission has been created to attend to the details. One San Francisco instrument manufacturer has sold over 1,000 rain gages, and other manufacturers have sold almost as many. In the course of a year the San Francisco office of the Weather Bureau reluctantly declines more than 300 offers of individuals who are willing to keep climatological records without compensation if the necessary apparatus is furnished. Rainfall is considered of such importance that when precipitation occurs the data are invariably given first-page space in the leading daily newspapers. Thousands of windmills in the agricultural regions are in operation daily during the dry season pumping water for irrigation purposes. The railroads which cross the Sierra Nevada Mountains are able to operate only because of snowsheds. Mountain observatories at Lick Observatory, Mount Wilson, Squirrel Inn, and Summit are collecting data which offer the student of mountain climatology excellent research material. Insurance against unfavorable weather is a legitimate activity which has become firmly established in California, and is destined to grow to large proportions in the future. The principal kinds of unfavorable weather for which insurance is now purchased are frosts, hail, floods, and rainfall during the fruit-drying and rice-harvesting seasons.

These are only the most conspicuous examples of the practical application of climatology in California.

THE APPROXIMATE NORMAL TEMPERATURE AS A FUNCTION OF THE LATITUDE, ELEVATION, TIME OF DAY, AND DAY OF THE YEAR.

By FRANK L. WEST, Ph. D., Physicist.

[Utah Agricultural Experiment Station, Logan, Utah, Dec. 20, 1920.]

SYNOPSIS.

In an earlier contribution, it was shown that the following empirical equation gives the normal temperature at any hour of any day with an average error of 2.75° F.:

$$t=M+\frac{R}{2}\cos d+\frac{r}{2}\cos h+\frac{V}{4}\cos d\cos h \quad . . . (1)$$

in which M is the average annual temperature, R the annual range or the difference between the mean of the day with the highest normal temperature and that with lowest, r the daily range, V the difference between the daily ranges at the coldest and warmest times of year, d the time of year, and h the time of day. Beginning at the time of maximum temperature, d and h are expressed in degrees 0 to 360, and with 180 at the time of minimum temperature even though this makes each degree of h from 180 to 360 represent shorter intervals of time than does each from 0 to 180.

In this new paper it is shown that the constants in the above equation can be expressed fairly accurately by the following equations which apply to the United States east of the 100th meridian:

$$M=110-1.4l-0.002\ E \quad . . . (2)$$

where M is the mean annual temperature, l the latitude, and E the elevation (expressed in feet) above sea level;

$$R=-24+1.8l \quad . . . (3)$$

where R stands for the annual range in temperature and l for the latitude. The daily range r is sensibly constant and has a value of 18° F., and V is zero.

Equation (1) with these substitutions reduces to

$$t=110-1.4l-0.002\ E+(0.9l-12)\cos d+9\cos h \quad . . . (4)$$

For the arid West the following equation applies very approximately:

$$M=121-1.4l-0.0033\ E \quad . . . (5)$$

The other values are sensibly constant all over this area and have the following values: One-half the annual range is 23°, one-half the mean daily range is 11°, and one-fourth the variation in the daily range 3°.

Equation (1) becomes on substitution of these values for the arid West of the United States:

$$t=121-1.4l-0.0033\ E+23\cos d+11\cos h+3\cos d\cos h\ . \quad (6)$$

The mean error in the use of equations (2), (3), and (5) for places all over the United States except the humid Pacific coast was ±1.1° F., and in the use of equations (4) and (6) giving the normal temperature as a function of the latitude, elevation, and time ±3° F.

In an earlier contribution,[1] the normal temperature at any hour of the day was expressed as a function of the annual mean, the annual range, the daily range, the time of year, and the time of day. It is the purpose of this paper to consider this relationship further, introducing the additional considerations of latitude and elevation. Only two of the three sections into which the United States was divided will be considered here, namely, the region east of the 100th meridian, and the region between the Rocky Mountains and the Sierra Navada-Cascade Mountains. To facilitate consideration of the new factors enumerated above, places of nearly the same latitude were selected in considering the effect of elevations, and, in considering latitude, places of nearly the same elevation were selected. Where these conditions were nearly, but not quite satisfied, a slight correction was introduced to bring the data to a common latitude or elevation, respectively.

Mean annual temperature and elevation above sea level.—Figure 1 represents the elevation above sea level and the mean annual temperature of about 100 cities distributed over the eastern part of the United States, these values having been reduced to the same latitude. The arid West is shown by the dotted line. A range from sea level to 2,000 feet was selected in the first case and from 3,000 to 6,000 feet above sea level in the second because most of the territory of these divisions has these respective ranges of elevation. The temperature gradient is not constant, the value for the low section being 0.002 and for the high western section 0.0033 (500 and 300 foot rise to 1° F. colder); and yet over the range of each separate land division the gradient is sufficiently constant for all practical purposes, as shown from the fact that the straight line fits the data so well.

Temperature and latitude.—Figure 2 shows the manner in which the mean annual temperature M changes with the latitude l over the East.[2] All temperatures were reduced to the equivalent sea-level values. The arid West is shown by the dotted line. For both sections it is clearly seen that the temperature decreases rather regularly as the latitude increases, the change being 1.4° F. for each degree of latitude, the gradient being the same for both sections.

Temperature, latitude, and elevation.—The equation which fits the above data for the eastern division is:

$$M=110-1.4l-0.002\ E \quad . . . (2)$$

where M represents the mean annual temperature, l the latitude, and E the elevation above sea level in feet. This equation checked against actual values for 26 cities selected at random over 23 States showed a departure of ±0.9° F. That for the arid West is:

$$M=121-1.4l-0.0033\ E. \quad . . . (5)$$

This equation checked against cities widely separated over all the arid States of the Great Basin gave a departure of ±1.3° F.

Range of the annual march.—Figure 5 shows the manner in which the difference in temperature between summer and winter, or the annual range in temperature, varies with the latitude for the eastern part of the United States. In general, the range is least for oceanic sections and most for continental areas, but probably because of the prevailing westerly winds the Atlantic Ocean has slight effect on the coast cities, the range being nearly the same there as for cities of the same latitude in the interior. The Gulf of Mexico seems to have a marked effect on the annual variation. It has a minimum value on the shores of the Gulf and increases very regularly by 1.8° F. for each degree of latitude north. The equation representing this relationship for the eastern division is:

$$R=-24+1.8l \quad . . . (3)$$

where R stands for the annual variation or range and l for the latitude. Results from equation (3) compared with

[1] West, Frank L. A Simple Equation of General Application for the Normal Temperature in Terms of the Time of Day and the Day of the Year. MO. WEATHER REV., July, 1920, 48: 394-396. Cf. also *Science*, Dec. 24, 1920, p. 611.

[2] The greater the annual rainfall the smaller the mean annual temperature, the correction being approximately 0.02° F. for each inch of rain. The area considered has a rainfall varying from 35 to 50 inches, and this variation of 15 inches would only amount to less than ½° F.; hence, the rainfall term was not used in the final equation.

actual values of 26 cities representing 23 States showed a mean departure of $\pm 0.9°$ F.

In the arid West, which is shut in by the Rocky and Sierra Nevada Mountains, the average annual range for 25 cities scattered over the southern half of the division differed from the average of a like number for the northern half of the same area by only $\frac{1}{4}°$ F., showing that the range is not simply a function of the latitude for this territory. The mean annual range for the entire district was 46° F. One-half of this value, or 23, is used in equation (6). The mean departure from this value of 23° by the different cities is 1.0° F.

Daily range in temperature.—The difference between the 6 a. m. and 3 p. m. temperatures (maximum and minimum) is nearly constant for all points of the eastern division and for all seasons of the year and has a value of approximately 18° F. One-half of this value, or 9°, is

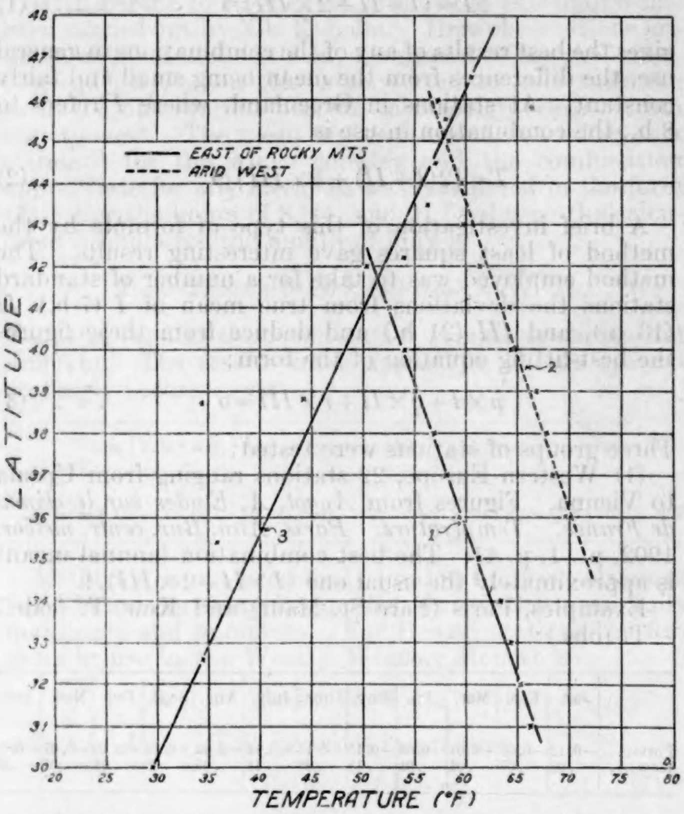


Fig. 1.—Graphs showing the changes in the mean annual temperature (in degrees Fahrenheit) with latitude, in the eastern and arid West portions (1) of the United States. Graph showing how the annual range in temperature (in degrees Fahrenheit) changes with the latitude for the United States east of the Rocky Mountains.

used in the formula, and the departure from this mean of the different cities was 1.4° F.

For the arid West the mean daily range, r, for all the days of the year is 22°, and the difference, V, between this value for a day in summer and for a day in winter is 12°. One-half and one-fourth of these values, 11 and 3, respectively, are used in equation (6) and the values for individual cities do not differ appreciably from these values.

The coefficient of the last term of equation (4) for the eastern division and the last three coefficients of equation (6) for the entire western or arid region were taken as constants. The actual variations in these values for different cities are usually no more than 1° F. It should be borne in mind that these constants simply specify the height of the crests of the curves above the mean. They are half the annual range and half the daily range. Even if the value for a particular city were to depart as much as 2° F. from these, yet the actual curve of normals for the city when superposed on the curve of means for the area would simply have its crest 1° F. above and its trough 1° F. below that for the equations, and the curves would coincide at the mean and very nearly so all the way up the curve until very nearly to the crest. There, of course, the error would be the full 1° F. The small variations, therefore, in these constants make less difference in the final result than would at first appear and, besides, the variations in the constants themselves are small.

When these values for M, R, r, and V are substituted in the general equation given in the earlier paper, viz,

$$t = M + \frac{R}{2}\cos d + \frac{r}{2}\cos h + \frac{V}{4}\cos d \cos h$$

the approximate normal hourly temperature for a city in the eastern United States or for one in the arid West can

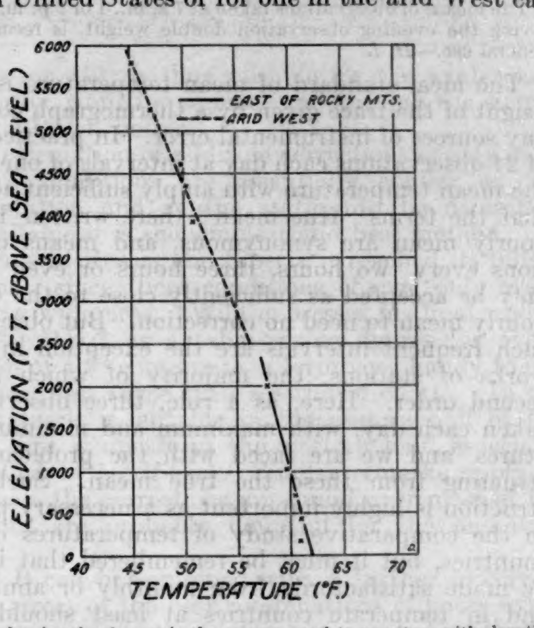


Fig. 2.—Graph showing the changes in the mean annual temperature with elevation in the United States.

be computed from the latitude and altitude of the place, the equations becoming

$$t = 110 - 1.4l - 0.002\,E + (0.9l - 12)\cos d + 9\cos h \quad \text{(East)} \qquad (4)$$

$$t = 121 - 1.4l - 0.0033E + 23\cos d + 11\cos h + 3\cos d\cos h \quad \text{(arid West)} \qquad (6)$$

These final equations (4) and (6) are interesting, inasmuch as they apply to such a large area of country, and they are thus rather general. However, their test is: Do they fit the facts? The mean difference between the actual normal hourly temperatures and those obtained by equation (1) was 2.75° F. In using equations (2), (3), and (5) it was 1.1° F., and with the use of equations (4) and (6) it was $3\frac{1}{2}°$ F. Actual temperatures differ from the normals, and equations (4) and (6) will give the actual temperature experienced at a particular hour on a particular day usually within 5° F.

Equations (4) and (6) have practical value in such cases as the determination of early morning temperatures where heating to protect crops from frost is practiced, in calculating hourly values where thermograph records have not been taken, and for engineers engaged in laying concrete in determining the normal time in the spring and fall when freezing temperatures are experienced during working hours.

TRUE MEAN TEMPERATURE.

By C. E. P. BROOKS.

[Meteorological Office, London, Feb. 7, 1921.]

SYNOPSIS.

The complexity of the question of obtaining the true mean temperature led the late A. Buchan to look favorably on the mean daily extremes (maximum plus minimum)/2 as an expression of the mean temperature. This view has become traditional among English-speaking races, but it has two very grave objections, and it is not adopted by continental or South American meteorologists. These objections are briefly: (1) Maximum and minimum thermometers, especially the latter, are far more likely to develop systematic errors than is the ordinary dry bulb. This remark applies with great force to hot countries, where in addition the observers are frequently untrained. In fact, it was this very difficulty which led to the adoption of a column of "True mean temperature" in *Reseau Mondial*. (2) The relation (maximum plus minimum)/2 to the true mean is not even approximately fixed, but varies with the location, with the cloudiness, and with the time of year.

The means of observations taken at 7 a. m., 1 or 2 p. m., and 9 p. m., giving the evening observation double weight, is recommended for general use.—*H. L.*

The ideal standard of mean temperature is the mean height of the trace given by a thermograph corrected for any sources of instrumental error. In practice the mean of 24 observations each day at intervals of one hour gives the mean temperature with amply sufficient accuracy, so that the terms "true mean" (here written T.) and 24-hourly mean are synonymous, and means of observations every two hours, three hours or even four hours may be accepted as sufficiently close to the true or 24-hourly mean to need no correction. But observations at such frequent intervals are the exception in most networks of stations, the majority of which are of the second order. Here, as a rule, three observations are taken each day, with maximum and minimum temperatures, and we are faced with the problem of reconstructing from these the true mean. Such a reconstruction is highly important as a necessary preliminary to the comparative study of temperatures in different countries, but it must be remembered that it can only be made satisfactorily from monthly or annual means, and in temperate countries at least should never be employed for individual days. The methods adopted in various publications fall under four heads:

(A) The combination of the means of the observations at the three fixed hours, or of the maximum and minimum in certain proportions which have been found to give approximately the true mean at "standard" stations where hourly observations are available.

(B) The calculation of appropriate additive corrections for various combinations of hours or for the mean of the maximum and minimum at standard stations, and their transference without modification to other stations in the vicinity. A development of this method is to plot the corrections at standard stations on maps, and read off the corrections at intervening stations from these maps.

(C) The corrections at the standard station may be multiplied by a factor proportional to the daily range (or to the difference, midday-evening observations) at the station to be corrected.

(D) All direct use of standard stations may be avoided and the reduction to true mean based on considerations connected with the general phenomena of the diurnal variation of temperature.

A and B may be described as "mechanical" methods, since they take no direct account of the diurnal variation, while C and D, which are based on the existence of a normal diurnal curve, may be described as "logical." But it can not be stated dogmatically that any one of them is better than the others. Each has advantages in special cases; for example, methods A and D are of value where the stations are isolated or the hours of observation irregular, B is the obvious method over the wide plains of Siberia or America, and C has advantages in the complicated relief of Norway. Every case must be considered on its merits.

A. The most general combination of hours is 7 h., 13 or 14 h., and 21 h; call the observations at these hours *I*, *II*, and *III*, respectively. The direct mean $(I+II+III)/3$ is too high. The mean

$$T=(I+II+2\times III)/4 \qquad \ldots \quad (1)$$

gives the best results of any of the combinations in general use, the differences from the mean being small and fairly constant. At stations in Greenland, where *I* refers to 8 h., the combination in use is

$$T=\{2(I+II)+5\times III\}/9 \qquad \ldots \quad (2)$$

A brief investigation of this type of formula by the method of least squares gave interesting results. The method employed was to take for a number of standard stations the deviations from true mean of *I* (7 h.), *II* (13 h.), and *III* (21 h.) and deduce from these figures the best-fitting equation of the form:

$$p\times I+q\times II+r\times III=o \qquad \ldots \quad (3)$$

Three groups of stations were tested:

(1) Western Europe, 22 stations ranging from Upsala to Vienna. Figures from *Angot, A, Etudes sur le climat de France. Température. Paris, Ann. Bur. centr. météor,* 1902, pt. 1, p. 41. The best combination (annual mean) is approximately the usual one $(I+II+2\times III)/4$.

Examples, Paris (Parc St. Maur) and Kew, T. (calc.) —T. (obs.):

	Jan.	Feb.	Mar.	Ap.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Paris....	−0.12	−0.08	+0.01	−0.09	−0.15	−0.15	−0.11	−0.03	+0.11	+0.10	−0.07	−0.12
Kew.....	− .08	− .07	− .01	− .01	− .18	− .23	− .18	− .05	+ .06	+ .04	− .05	− .09

(2) Subtropics, 22 stations. Figures from *Hann, J von, Die tägliche Gang der Temperatur in der aüsseren Tropenzone. Wien, Denkschr, Ak. Wiss.*, 80, 1906, p. 317; 81, 1907, p. 21.

The best combination is

$$(I+0.9\times II+1.1\times III)/3$$

which can also be written

$$\{I+II+III-\tfrac{1}{10}(II-III)\}/3 \qquad \ldots \quad (4)$$

This combination gave remarkably accurate results, the probable error of the true mean being only a fraction of a degree absolute.

Example, Mauritius, T. (calc.)—T. (obs.):

Error.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
$\{I+II+III-\frac{1}{10}(II-III)\}/3$.......	0.1	0.1	−0.1	0.0	−0.2	−0.2	−0.2	−0.2	0.0	0.4	0.6	0.1

(3) Tropics, 30 stations. Figures from *Hann, J. von, Die tägliche Gang der Temperatur in der inneren Tropenzone. Wien, Denkschr. Ak. Wiss.*, 78, 1905, p. 249.

The best combination is No. (4), but is not quite so exact as for subtropical stations. An alternative is

$$\{2(I+II)+3\times III\}/7 \qquad \ldots (5)$$

which is remarkably accurate at Batavia.

Example, Batavia, T. (calc.) – T. (obs.):

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
No. (4)..	–0.04	–0.04	–0.08	–0.09	–0.10	–0.11	–0.13	–0.13	–0.09	–0.06	–0.01	+0.01
No. (5)..	– .02	– .02	– .05	– .07	– .06	– .07	– .07	– .06	– .05	– .06	– .03	+ .01

For other hours the combinations would of course be different.

With regard to Sweden an interesting calculation has been carried out by Nils Ekholm.[1] Here observations are taken at all stations at 8 h., 14 h., and 21 h., *civil* time. Consequently, when this is converted to *local* time the hours of observation become increasingly earlier from east to west. The mean of five stations was taken as a standard for the whole country and the combination appropriate for any meridian was calculated in the form (3). For the hours of 8, 14, and 21 *local* time the calculated formula for the month of May is

$$T=0\cdot 27\times I+0\cdot 20\times II+0\cdot 53\times III \qquad \ldots (6)$$

For other months the coefficients p, q, and r are somewhat different. The results when applied to Upsala are exceedingly accurate, viz:

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
49 years mean..	–0.01	–0.01	+0.03	+0.01	–0.02	–0.05	–0.05	0.00	+0.03	–0.02	–0.01	0.00

Method A is not necessarily limited to observations at fixed hours, but may be applied also to the mean daily maximum and minimum. For British stations the formula in use in the Weekly Weather Report is:

$$T=k\times M+l\times m\ ^{2}$$

where $k+l=1$. This becomes in practice:

$$T=m+k\ (M-m) \qquad \ldots (7)$$

k was determined empirically by reference to standard stations, and is a constant which varies only with the month.

At many stations the observations at fixed hours are combined with M and m in empirical formulæ. A few examples are:

Hamburg: May to August $(8+20h+M+m)/4$. (8)
September to April $\frac{1}{2}\{(8+20h)/2+(8+14+20h)/3\}=(5\times 8h+2\times 14h+5\times 20h)/12$ . . . (9)

Tunis: $\{7+13+19h+\frac{1}{2}(19h+m)\}/4$ . . . (10)

Egyptian stations: $(8+14+20h+m)/4$ . . . (11)

This combination gives values which are too low; better results would be obtained by substituting M for 14 h.

[1] Stockholm, Institute Central de Météorologie. Vol. 56, 1914, App: Calcul de la température moyenne mensuelle de l'air aut stations météorologiques suédoises. Uppsala 1916.

[2] M is employed throughout as the symbol for mean daily maximum, and m for mean daily minimum.

For Cairo (Abbassia) we have the following values of T. (calc.) – T (obs.):

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
$(8+14+20h+m)/4$.	–1.1	–1.0	–1.0	–1.0	–0.8	–0.8	–0.5	–0.6	–0.5	–0.8	–0.9	–0.9
$(8+20h+M+m)/4$.	– .8	– .7	– .6	– .5	– .4	– .4	– .2	– .3	– .3	– .5	– .6	– .6

Ponta Delgada: $(9+21h+M+m)/4$ . . . (12)

This is a good combination for stations under a great variety of conditions, since $\frac{1}{2}\ (M+m)$ is too high and $\frac{1}{2}\ (9+21h)$ is too low, and the errors partially balance each other. For example, at Naha, Liu Kiu Islands:

Correction for—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
$\frac{1}{2}\ (9+21h)$	+0.28	+0.19	+0.18	+0.04	0.00	+0.08	–0.01	–0.01	–0.06	–0.05	–0.01	+0.20
$\frac{1}{2}\ (M+m)$	– .22	– .17	– .20	– .31	– .26	– .48	– .43	– .38	– .52	– .24	– .16	– .18
Mean....	+ .03	+ .01	– .01	– .13	– .13	– .20	– .22	– .19	– .29	– .14	– .09	+ .01

Combination (12) is thus suitable for the winter and spring months, while for summer and autumn the simple mean $\frac{1}{2}\ (9+21h)$ is better.

B. The calculation of additive corrections is only suitable where conditions are essentially similar at the standard station and at the station to be corrected. Where available it is the simplest and best method. In Wild's hands in Russia and Siberia it reached its fullest development, since there conditions change only gradually over a wide area. Wild expresses his final results for $(7+13+21h)/3$ as a table giving figures for every intersection of a 5°-coordinate, a form very handy to use and requiring less space than a series of charts. In the United States it is suitable in the eastern half of the continent, but is unsafe in the western half, especially when applied to $\frac{1}{2}\ (M+m)$. Similar remarks apply to India,[3] where the corrections are sound over most of the country but are probably doubtful for the mountain stations.

Method B can be combined with A further to correct the slight errors of the best combinations of hours available. An example is the Chilian network, where the following additive corrections have been found for the combination $(I+II+2\times III)/4$, the hours of observation being 7, 14, and 21 h.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mollendo (Peru)..	+0.2	+0.2	+0.2	+0.3	+0.2	+0.1	+0.1	+0.1	+0.1	0.0	0.0	+0.1
Santiago.........	– .4	– .2	.0	+ .2	+ .2	+ .1	+ .1	+ .2	+ .1	– .1	– .3	– .4
Punta Arenas.....	.0	.0	+ .1	+ .1	.0	.0	.0	+ .1	+ .1	.0	.0	– .1

It would have been better if Wild had employed this compound method for use with the Russian stations, as the mean $(7+13+21h)/3$ involves considerable corrections in summer, e. g. Nertchinsk.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
$(7+13+21h)/3$..	–0.28	+0.01	+0.07	–0.26	–0.37	–0.50	–0.42	–0.24	–0.05	–0.02	–0.23	–0.33
$(7+13+2\times 21h)/4$	– .09	+ .16	+ .27	+ .06	+ .01	– .11	– .03	+ .14	+ .25	+ .21	– .05	– .11

C. In countries of varied relief it is not safe to assume that the diurnal variation is similar at two neighboring stations. The amplitude especially may show considerable fluctuations between, say, hill stations and valley

[3] Calcutta, Meteor. Office. Indian Meteor. Memoirs, vol. 17, Calcutta, 1904.

stations. To meet this difficulty Kämtz suggested the following method [4] for use at stations where observations are taken three times daily: Find the difference $II - III$ at the standard station and at the station to be reduced, call these values "s" and "a," respectively. Let Cs be the additive correction to $(I + II + III)/3$ at the standard station. Then the additive correction at the station to be corrected is given by

$$Ca = Cs \times (a/s) \quad . \quad . \quad (13)$$

This should eliminate the influence of the amplitude. But it appears that at stations with similar climates the amplitude is similar, and if the climates are dissimilar, the method is hazardous. For example, let us take the case of Los Andes, in a valley at the foot of the Andes,

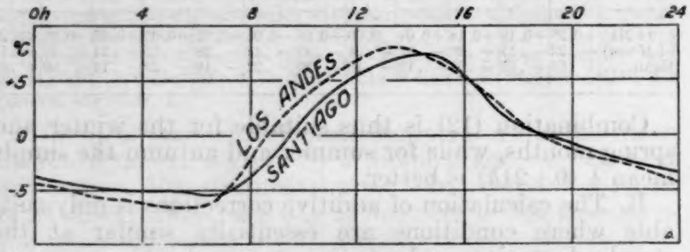


FIG. 1.—Diurnal variation at two neighboring stations. The range is similar but the shape of the curves differ.

and the neighboring station of Santiago, on the coastal slope. In July 1912 we have for the hours of 7, 13, and 21 h.:

	I	II	III	$II-III$	a/s	$(I+II+III)/3$	Correction. Obs.	Correction. Calc.	T. (Calc.).	T. (Obs.).
Los Andes, °C	4.7	18.0	8.3	9.7	0.87	10.3	−0.6	......	......	9.7
Santiago, °C	2.3	13.9	5.5	8.4		7.2	......	−0.5	6.7	7.1

Here the required corrections for Santiago was -0.1, and the correction found was -0.5. Drawing the curves of hourly temperatures (fig. 1) it is seen at once that the source of the error is the sharp right minimum at Los Andes.

The method has been developed by Mohn for use at Norwegian stations into the formula:

$$T = n - k(n - m) \quad . \quad . \quad . \quad (14)$$

where n is the mean of the three fixed daily observations and k is a factor varying with the station and month. The genesis of the formula is as follows: Write $n = (I + II + III)/3$ and give m the variable coefficient β. Then we have

$$T = (3n + \beta m)/(3 + \beta) = n - \beta(n - m)/(3 + \beta)$$

whence $k = \beta/(3 + \beta)$; β can readily be found for standard stations. Maximum thermometers are not in use in Norway.

A somewhat similar method was developed independently in the case of Horta, where observations are taken at 9, 12, 15, and 21 h. The mean of these four observations is obviously too high and the formula adopted was

$$T = (9 + 12 + 15 + 21h)/4 - k(M - m) \quad . \quad . \quad (15)$$

By comparison with Ponta Delgada k was given the value 0.13, which is valid throughout the year.

[4] Lehrbuch der Meteorologie, Leipzig, 1831, Bd. 1, p. 89.

D. In many tropical regions no standard station can be found near enough to be of value in a direct reduction. This is peculiarly the case in Africa, where the difficulty was further complicated by the great diversity in the hours of observation. After much consideration a method was adopted which did not involve the direct use of standard stations, the corrections being based on a consideration of the normal diurnal variation of temperature as expressed by the Fourier series

$$T_h = T + a_1 \sin (t_h + A_1) + a_2 \sin (2t_h + A_2) \, . \, . (16)$$

A detailed description of the method has been reported to the Royal Meteorological Society,[5] but the more important formulæ are reproduced here. Using absolute degrees, a_1 and a_2, the coefficients of the first and second harmonics, are calculated from the equations

$$\left.\begin{array}{l} a_1 = -0.72 + 0.44(M - m) \\ a_2 = +0.54 + 0.08(M - m) \end{array}\right\} \quad . \quad . \quad . \quad (17)$$

(1) Given three observations a day at intervals of six, six, and twelve hours (e.g., 6, 12, 18 h) we have

$$T = (I + 2 \times II + III)/4 - a_1 \times k \quad . \quad . \quad . \quad (18)$$

where $k = \frac{1}{2}(1 - (I - III)^2/4a_1^2)^{1/2}$.

This formula is not difficult to use and is generally accurate to less than $0.2a$. The chief uncertainty lies in the calculation of a_1 by (17).

(2) Given three observations, the first and last not separated by 12 hours,

$$T = p \times I + q \times II + r \times III - a_2 \times h \quad . \quad . \quad (19)$$

where p, q, r, and h depend solely on the hours of observation. For details the original paper must be consulted. Where the hours are 7, 13, or 14 and 21 h. it is better to use $(I + II + 2 \times III)/4$ or one of its variants.

(3) Given two observations a day separated by 12 hours (I and III), we have

$$T = (I + III)/2 + a_2 \times l \quad . \quad . \quad . \quad (20)$$

where l depends chiefly upon the hours of observation. For observations at 9 and 21 h. at stations within the Tropics we may take $l = 0.4$, for 8 and 20 h. $l = 0.8$: Thus we have, for 9 and 21 h.

$$T = (I + III)/2 + 0.03(M - m) + 0.2 \quad . \quad . \quad (21)$$

This is quite a useful formula.

In this paper some attempt was made to deduce additive corrections to $\frac{1}{2}(M + m)$ which should be generally applicable in the Tropics, and a table was compiled giving the correction in terms of $(M - m)$ and ϕ. The latter symbol stands for the term $2A_1 - A_2$, where A_1 and A_2 are the phase angles of the first and second terms of the Fourier series. ϕ is calculated from an empirical formula involving the latitude, the height, and the cloudiness. Some more direct method is obviously desirable, and for the tropical and subtropical regions between 30° N. and 30° S. a simple empirical formula has been calculated involving only the height and the mean daily range. The stations were divided into two groups, and for each station 36 monthly means were taken from the *Reseau Mondial*, 1911-1913. From the figures the following parabolic equations were obtained. R is the daily range, $M - m$.

[5] Brooks, C. E. P. The reduction of temperature observations to mean of 24 hours and the elucidation of the diurnal variation in the continent of Africa. London, Q. J. R. Meteor. Soc., 43, 1917, p. 375. (8)

(1) Stations below 1,000 meters; mean height 68 m.:

$$T = (M+m)/2 - 0.30 - 0.0025R - 0.0030R^2$$

(2) Stations above 1,000 meters; mean height 1,922 m.:

$$T = (M+m)/2 - 0.23 - 0.14R + 0.0085R^2$$

From these two equations we may deduce the general one,

$$T = (M+m)/2 + (a + bR + cR^2) \quad . \; . \; . \; (22)$$

where

$$\left.\begin{array}{l} a = -0.30 \quad +0.04h \\ b = 0.00 \quad -0.07h \\ c = -0.0034 + 0.006h \end{array}\right\}$$ h being the height of the station in kilometers. The figures refer to absolute degrees.

A preliminary trial of this formula gave encouraging results, and it was tested for 23 stations for each month of 1914, giving 276 cases. The results showed that T (calc.) has a probable error of $0.18a$, so that the application of the method is distinctly worth while when no other means of correction is available.

The average difference, $\frac{1}{2}(M+m) - T$, is $0.5a$, and if this is applied as a constant correction, the probable error of the result is $0.23a$.

For the convenient application of formula (22) Table 1 has been constructed, showing the correction at various heights and with various ranges.

TABLE 1.—*Corrections to* $\frac{1}{2}$ *(M+m.)*

Daily range.	Height in meters.							
	0	500	1,000	1,500	2,000	2,500	3,000	3,500
a.								
4	−0.35	−0.42	−0.49	−0.56	−0.63	−0.70	−0.77	−0.84
6	− .42	− .50	− .58	− .66	− .74	− .82	− .90	− .98
8	− .52	− .59	− .65	− .72	− .78	− .85	− .91	− .98
10	− .61	− .67	− .70	− .73	− .76	− .79	− .82	− .85
12	− .79	− .76	− .73	− .70	− .67	− .64	+ .61	− .58
14	− .97	− .85	− .73	− .61	− .49	− .37	− .25	− .13
16	−1.17	− .94	− .71	− .48	− .25	− .02	+ .21	+ .44
18	−1.40	−1.04	− .68	− .32	+ .04	+ .40	+ .76	+1.13
20	−1.66	−1.14	− .62	− .10	+ .42	+ .94	+1.46	+1.98

THE MEAN OF THE DAILY EXTREMES.

The complexity of the question of obtaining the true mean temperature led the late A. Buchan in his strivings after uniformity to look favorably on the mean of the daily extremes $(M+m)/2$ as an expression of the mean temperature. This view has become traditional among the English-speaking races, but it has two very grave objections, and is not adopted by continental or South American meteorologists. These objections are briefly:

(1) Maximum and minimum thermometers, especially the latter, are far more likely to develop systematic errors than is the ordinary dry bulb. This remark applies with great force to hot countries, where in addition the observers are frequently untrained and adequate inspection or comparison of readings is impossible. This has been brought out repeatedly in preparing normals for use in the *Reseau Nondial*, and it was in fact this very difficulty which led to the introduction of a column for "True mean temperature."

(2) The relation of $(M+m)/2$ to true mean is not even approximately fixed but varies with the location, with the cloudiness and with the time of year. The absolute range of the necessary correction, taking the monthly mean as the unit, is from about $1a$ to $-2a$, three degrees absolute, which is a very considerable degree of uncertainty. In cases of doubt Hann frequently assumes a correction of $-1a$, but this is too great, as we have seen. Assuming a correction of $-0.5a$ for the Tropics, we are faced with a probable error of $0.23a$, whereas in the case of most of the reductions based on observations at fixed hours the probable error is less than $0.1a$.

It is at subtropical desert stations that the anomalous values of $T - (M+m)/2$ are chiefly found. At these

FIG. 2.—Diurnal variation at Batavia (humid) and Tabora (Tanganyika Terr.) (dry). Note the sharp minimum at the latter station.

stations, where the air is very dry, nocturnal radiation is strong, and temperature continues to fall at an almost uniform rate throughout the night, giving a sharp minimum about sunrise (fig. 2, Tabora). On the other hand at stations where the air is humid the rate of fall slows down after a few hours, and the minimum is not sharp (fig. 2, Batavia). Hence at desert stations the minimum is much farther below the mean temperature of the night than at humid stations. The maximum temperature of the day is also affected, but not to the same extent, so that the sharp minimum at desert stations lowers the mean of the daily extremes relatively to the true mean, and the correction to reduce the former to the latter may be positive instead of negative. The irregularity of the correction at desert stations is due to the fact that a small difference in the slope of the curve before dawn, such as may easily be introduced owing to the great variability of the humidity in such situations, makes a great difference in the minimum temperature but has little influence on the 24 hourly mean.

CONCLUSION.

The conclusion to which all this tends is that meteorologists in the English-speaking countries would be well advised to make a less exclusive use of the mean of the daily extremes and to place more reliance on observations at fixed hours, the best combination being $(7 + 13 \text{ or} 14 + 2 \times 21)/4$.

THE SECULAR VARIATIONS OF CLIMATE.

By J. PARASKÉVOPOULOS.

[Weather Bureau, Washington, D. C., May 19, 1921.]

Dr. J. Paraskévopoulos, the author of this article, is a representative of the Astronomical, Meteorological and Seismological Observatory of Greece. He has been in the United States for the past two years studying at the astronomical observatories at Williams Bay, Wis., and Mount Wilson, Calif. At the time of the preparation of this article, he was spending two months in the study of meteorology at the United States Weather Bureau, at Washington.—EDITOR.

SYNOPSIS.

After a brief discussion of the secular variations of the climate of the earth, the following theories, proposed for the explanation of these variations are described. None of these theories is sufficient to account for the known variations of climate, and some require dynamical conditions which are not in accord with celestial mechanics. These theories are:

1. The effect of the temperature of the interior of the earth.
2. Emanations of radioactive substances in the earth's crust.
3. Variations of solar energy according to Russell's theory of stellar evolution.
4. Variations of the inclination of the earth's axis (precessional motion and variations of latitude).
5. The "pendulation" theory.
6. Variations in the carbon dioxide content of the air.
7. Volcanic action; dislocation of parts of the earth's crust; distribution of sea and land.
8. Cosmic causes.

It is concluded that no single theory is likely to be the right one, but that the factors represented by several combine to give the known secular variations of climate.

Undoubtedly the question of the secular variations of the earth's climate is one of great importance and of intimate connection with the theory of the evolution of our planet. The investigation of this problem has been, for a long time, the subject of discussion among scientists; and lately, under the title "An Astronomical Explanation of the Glacial Periods," in the *Scientific American Monthly* for November, 1920, Mr. F. J. B. Cordeiro made an attempt at explaining the glacial periods by supposing a change of the inclination of the earth's axis with respect to the ecliptic and by assuming the possibility of demonstrating such a change.

The writer does not intend to give a new explanation of the problem, but simply to summarize as briefly as possible the outlines of this important question, and to point out the direction in which the real interpretation seems to lie.

Whatever the origin of our planet and the solar system itself may be, there is absolutely no doubt that every body in the universe is undergoing a slow, but steady and continuous, evolution. The powerful instruments which lately have been placed in the hands of scientists clearly show continuous changes of the celestial bodies even within a short interval of time: The famous Great Red-Spot of Jupiter, which appeared suddenly about 50 years ago and which has almost disappeared; the continuous fluctuations of solar energy; the phenomena of the variable stars, which can not be explained as eclipse phenomena; the novæ; Hubble's variable nebula; the variability of the Crab nebula in Taurus (Messier 1) recently detected by Lampland at Flagstaff, Ariz., and verified at Mount Wilson, Calif.; the earth's volcanic action and the continuous dislocation of its strata. These prove clearly that evolution is a natural law in the history of the universe.

The place of the earth amid the other members of the Sun's family makes the study of its evolution very complicated and uncertain. The earth is subjected (1) to its own forces, and (2) to the influence of the members of the solar system beginning with the sun. There is no doubt that the most important element controlling the earth's climate is temperature, and as far as we know the temperature changes do not seem regular or of the same sign since the earlier geological periods.

Temperature of the earth's interior.—Years ago, it was believed that the high temperature of the interior of the earth should have a certain influence on the outside, at least in the earlier periods as far as the Tertiary. However, according to the results of the investigation of the thermal conductivity of the different strata forming the earth's crust, and the study of the fossils of the earliest geologic periods, the earth's interior heat can by no means explain the temperature variations on its surface, such as the glacial periods.

Radium.—On the other hand, according to Strutt and Rutherford, a normal distribution of radium of only $\frac{1}{5700}$ to $\frac{1}{8600}$ milligrams per cubic meter of the earth is enough to counterbalance the loss of the earth's heat by radiation. No one knows, of course, the quantity of radium in the earth's mass, and consequently we have no means of checking that theory.

Solar influence.—The influence of the solar heat upon the earth's climate is unquestionable and its effects do not need to be described here. However, the very difficult point in that problem is to discover the laws of the variability of that action during the different geological periods and also to find if other factors have contributed to a certain extent.

The geological history of our planet shows that the variations of its surface temperature were not continuous and in one direction only—as has been said above—and this fact introduces more difficulties in the general problem. Prof. H. N. Russell's theory of the evolution of the stars, based on the frequency of their absolute magnitudes relative to their spectral types, regards the sun, as it is now, as a dwarf, late-type star. According to this theory, the sun started as a giant star of late spectral type and low temperature, reached its maximum temperature after passing through the successive spectral types from the latest to the earliest, and now, is cooling and following the descending branch of stellar evolution.

There are many strong evidences supporting Russell's theory, and if this is the case with our sun, undoubtedly the enormous range of its temperature during the process described above, should have had a great influence upon the earth. As is well known, we try to guess and to find the cause of the secular variation of climate by means of the marks of the various influences on the earth's surface; and these marks are so complicated that it is impossible to regard the variation of the sun's heat as the only cause of terrestrial atmospheric phenomena.

Changes of the pole.—The fact that the climatic zones are arranged perpendicularly to the axis of diurnal rotation, implies that any change of the pole must produce corresponding climatic changes on the earth. The change of the polar axis presents two aspects: (1) Precessional motion of the axis itself, that is to say a motion of the earth such as is illustrated by the gyroscope; and (2) change of the rotation axis relatively to the earth, that is to say, change of the location of the poles on the earth's surface. Both phenomena are very well known to astronomy, the first as precession and nutation, and the second as the secular variation of geographic latitudes. The amount of the precessional

motion of the axis is about 47° in 25,800 years. This period, in spite of its enormous length, can not explain the climatic variation of the past geologic periods, except a mutual change of climate between the northern and southern hemispheres. As regards the displacement of the poles on the earth's surface, the amount of the motion is, to-day, negligible.

Mr. Cordeiro tries to develop a theory of the displacement of the earth's axis in the earliest time on the basis of the moon's tidal effect, and thus to explain the cause of the glacial periods of the earth. A discussion of his theory is beyond the limits of the present article.

"Pendulation" theory.[1]—According to the "pendulation" theory, the earth, besides its rotation on its axis, is also swinging on an axis extending through the earth from Sumatra to Ecuador with an amplitude of from 30° to 40°. Each swing corresponds to a geological period. In the paleozoic period the motion brought Europe northward and reached in the Permean age the first glacial period. During the Mesozoic period, the swing changed southward and Europe reached the Cretaceous period with subtropical climate. In the Tertiary, the swing was again toward the north until the Diluvian, when the second glacial period occurred. Since then the swing changed toward the south, etc. It is not the aim of the present article to go into the details of the theory, but it is necessary to add that it does not explain fully the climatic changes during the different periods, and in the different parts of the earth's surface.

Other theories.—Besides the above-described theories, a number of different explanations also have been proposed. Arrhenius and others believe that the percentage of carbon dioxide of the earth's atmosphere has been different in the different periods. Others also tried to attribute the climatic changes to cosmic causes such as the change of the eccentricity of the earth's orbit, and others to volcanic action, to the dislocation of strata and to the distribution of the seas. In fact, no one of all these theories can offer a full explanation of the climatic changes.[2]

Conclusion.—It is believed to be beyond any doubt that the cause of the climatic changes in the different periods is not a single one and that these changes are a compound effect of a great many factors. The fact that no one of the above-mentioned theories can explain fully the climatic changes does not mean that all these theories are entirely wrong. It is very probable that several of the above reasons have contributed to a certain extent. It seems that, in trying to find the solution of this enigma, the best thing to do is to combine the possibilities instead of attributing the phenomenon to certain entirely isolated reasons.

[1] Cf. Simroth, Dr. Heinrich: Die pendulationstheorie, Leipzig, 1907; and Eckardt, Wilhelm R.: Paleoklimatologie, Leipzig, 1910.

[2] See W. J. Humphreys, Physics of the air, 1920, pp. 556-629; also Prof. Arldt, of Radelberg, in a publication under the title "Die Ursachen der Klimaschwankungen der Vorzeit, besonders der Eiszeiten," *Zeitschrift fur Gletscherkunde*, Band XI, p. 1-27, 1918, has grouped and discussed the different theories on the subject. An abstract of his article appeared in *Science*, Jan. 7, 1921, pp. 22-23.

THE FREEZING OF PEACH BUDS.[1]

By EARL S. JOHNSTON, PH. D.

[Author's abstract.]

[University of Maryland, College Park, Md., April, 1921.]

It is very desirable that some physical measurement of the hardiness of fruit buds be worked out before the relationship between various environmental conditions and the loss of fruit due to spring freezes can be determined definitely. Some experiments carried on at the University of Maryland Agricultural Experiment Station during the early part of the present year (January to March, 1921) indicate an increase in the tenderness of peach buds with the approach of spring. By means of a portable galvanometer and a needle-type thermocouple inserted in the bud which was then exposed to low temperature (about 7° F.) the freezing point of the sap within the bud could very easily be determined. Other data obtained indicate that wet buds freeze at higher temperature than dry buds. A period of cold weather immediately following a rain is thus apparently more dangerous to a peach orchard than cold weather alone. The accompanying table illustrates the change in resistance offered by peach buds of the Elberta variety to low temperatures.

Average determinations made from the lateral fruit buds of Elberta peach given in degrees Fahrenheit.

Date of experiment....	Jan. 21.	Jan. 26.	Feb. 12.	Feb. 18.	Feb. 25.	Mar. 5.	Mar. 11.	Mar. 14.
Temperature at which ice crystals formed..........	17.8	19.2	17.8	18.1	18.5	19.0	19.4	22.3
Freezing point of sap......	21.0	22.1	20.3	21.6	21.6	22.8	24.4	24.6

In the discussion of Dr. Johnston's paper, Dr. A. D. Hopkins mentioned an unusual feature in connection with the damage to foliage in the freeze of March 29, 1921. On some Ginkgo, mulberry, and even some apple trees there were whole branches on which the leaves and flowers suffered no damage whatever, while all the green parts on the other branches of the same trees were killed. Dr. Hopkins marked these with copper tags, in order to see if in future springs when freezes occurred the same branches showed corresponding hardiness. If they do, as seems likely, it would appear advisable to grow cuttings from these hardy branches and in that way develop a frost-resistant tree. This would be of great value in fruit raising.

[1] Presented before American Meteorological Society, Washington, D. C., Apr. 20, 1921.

FROST AND FRUIT IN SOUTHERN OHIO IN 1917.

WILLIAM H. ALEXANDER, Meteorologist.

[U. S. Weather Bureau, Columbus, Ohio, December, 1917.]

As is well known, most fruit crops in Ohio, especially southern Ohio, were very poor in 1917, and, of course, the botanist, the orchardist, the meteorologist, and in fact the public generally would like to know, if possible, the reason or reasons for this. Naturally, all turn to the weather for the most probable explanation. Under date of May 18, 1917, Prof. Selby (1) called the attention of this office to certain observed facts and conditions that seem to be of more than passing interest in regard to the effects of the weather during the preceding winter on apple, peach, plum, and cherry trees and buds. His letter follows:

The writer has been much impressed by the unusual severity of the past winter's freezing injury to peach trees in southeastern Ohio, and likewise by the unusual damage in the destruction of fruit buds on sour cherry and European plum in the same district.

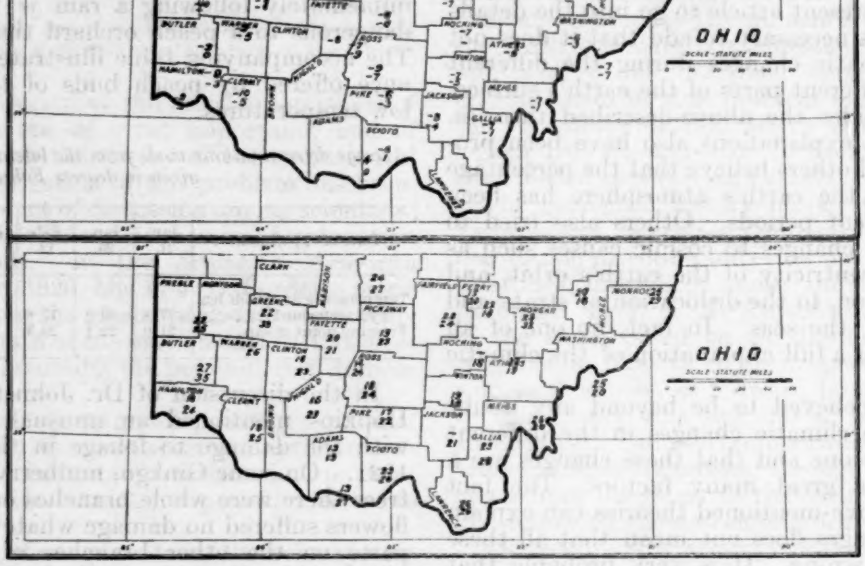


FIG. 1.—Minimum tepmperatures Feb. 5 (upper) and 12 (lower), 1917.
FIG. 2.—Minimum temperatures Apr. 9 (upper) and 14 (lower), 1917.

The curious feature of this injury which appealed to me in going over Lawrence, Gallia, Meigs, Athens, Washington, and Morgan Counties during the period from May 3 to 9, is the greater severity of the injury on the higher altitudes. This indicates injury during a period of high winds and low temperatures combined. These lowest temperatures through the district, as shown in the February number of "Climatological Data" (pp. 12, 16), indicates the second cold period of February, namely, February 11–13, as the most probable period in which this injury was caused.

I have recently been advised by correspondence of the killing back of 4-year-old peach trees near Pennsville, Morgan County, and of injury to apple and prunus fruits in Belmont County. Has your department any data for the more specific mapping of the minimum temperatures and wind velocities for these February storms in 1917?

I have noted that sour cherry in the lower altitudes has come through with comparative success, and blooming freely. Likewise in this district, although more generally the fruit buds of peach are killed here and in the southeastern district.

Indeed, I was not prepared personally for the general freezing injury to sour cherry blossoms in southeastern Ohio until the recent May visit. When examined in some detail on March 26–27 there did not seem to be a very serious injury to the blossom buds of sour cherry upon my Selby Heights Farm orchard, Sharpsburg, Athens County (altitude 950 to 1,000 feet), but the actual blooming and present promise is very, very light indeed, and restricted to a relatively small number of trees.

Owing to the well-authenticated Easter freeze injury of burst or opening buds on varieties of apple over this same territory, it is not quite clear in my mind that all our Athens County injury dates back to February. Some of it on the cherry may be referable to the Easter freezing. Upon this point, however, I gather from Prof. V. H. Davis (2) of the Ohio State University that in his judgment it was the February or pre-February freezing that injured the blossom buds of sour cherry on their Poplar Ridge Fruit Farm in Ross County.

Any additional mappings of the second February freeze, or of the April centers of minimum temperatures will be appreciated.

To the above statement of facts should be added one or two details subsequently observed by Prof. Selby, also by Prof. Davis (2) and others, namely, that "the tips of peach twigs have all buds killed upon them in rather low ground near Harrison, Hamilton County, and at Mount Healthy, Hamilton County, on elevated ground," and that "the bare twigs, still green as to bark and appearance, projected above the starting shoots lower down."

All are agreed, of course, that there was very serious injury to fruit tree and bud resulting in the almost total loss of some fruit crops and the partial loss of others, but there is considerable difference of opinion as to just when the injury occurred. In looking back over the weather record of the preceding winter and early spring, one finds four or five periods of weather conditions sufficiently abnormal and severe to make it probable that the damage was done during any one of them, namely, February 5, February 11–13, April 9–10, and April 13–15, and early May. For the benefit of those interested in the study of the points raised by Prof. Selby, figures 1 and 2 show the extreme temperatures that prevailed at the various stations in southern Ohio during the cold spells mentioned in February and April; also graphs (fig. 3) showing the hourly temperatures and wind velocities for these same periods at the regular

Weather Bureau stations at Cincinnati, Columbus, Dayton, and Pittsburgh. Figure 1 shows the minimum temperatures on February 5 and 12, the upper number in each entry being the minimum for the 5th and the lower that of the 12th. Similarly, figure 2 shows the minima for the 9th and 14th of April.

In arriving at an adequate explanation of the unexpected extent and severity of the injury to the fruit buds noted above, one should not, of course, overlook the antecedent weather conditions, particularly as to moisture, that prevailed during the early stages of the buds. The records show, for example, that the preceding July was very dry, there being only about one-half the usual amount of rain and that of a rather local character, some sections, as in Adams, Athens, Fayette, Montgomery, Noble, and Perry Counties, receiving far less than 50 per cent of the normal amount. In fact, from June 22 to August 3, 1916, more especially from June 22 to July 15—a very important, not to say critical, period in the life history of the fruit bud—the rainfall was very light and local, resulting in some really severe droughty conditions that may possibly, in spite of good autumnal rains, account for the fact that the fruit trees entered the winter season in a reduced state of vitality and the further fact that the "fruit buds appeared to be flabby," the peach buds lacking "plumpness," as pointed out by Professor Green (3) and Mr. Speaker (4). Possibly the character of the soil on the uplands, or "higher altitudes" referred to by Prof. Selby, was such that the droughty conditions affected more seriously the growth and vitality of the trees on the uplands than on the lowlands and therefore the adverse weather conditions of the winter and early spring would naturally affect first and more seriously the weakest, tenderest parts of the tree, namely, the buds and the "tips of the twigs." However, the facts are, in so far as can now be gathered from the available records, that in the main the maturity and ripening of the fruit buds in the fall and early winter of 1916 were about normal, nor is there anything in the records to indicate a late-growth development of an abnormal type.

As an indication of the stage of development of the buds in the spring of 1917, we must of necessity rely upon the record at the Ohio Agricultural Experiment Station at Wooster, which is in the northern part of the State, but no doubt is typical. The figures are furnished by Mr. C. W. Ellenwood, assistant horticulturist at that station, and are for three standard varieties, namely, Ben Davis, Grimes Golden, and Rome Beauty.

Ben Davis: First blossoms, May 17; full bloom, May 22, 1917.

Grimes Golden: First blossoms, May 14; full bloom, May 21, 1917.

Rome Beauty: First blossoms, May 16; full bloom, May 24, 1917.

This, we are informed, is the latest development of fruit buds on the apple on record at the experiment station, even later by a few days than that of 1920. Assuming, then, that the development was correspondingly late in southern portions of the State, it seems highly improbable that there was a sufficient advance or swelling of the buds in 1917 to make them easily susceptible to injury from the cold weather in April, nearly a month before the blooming stage was reached.

Looking further into the weather conditions of the spring of 1917, we find that May was an unprecedentedly cool month, as indicated from the following extract taken from the introduction to the section report for that month:

> This was the coldest May in Ohio since the establishment of the Weather Bureau in 1871 and as cold as any other May in this State in more than 60 years. The average temperature for the State as a whole was 54.1°. This is just 7° below the normal and 13.8° below the high record of 1896. In 1867 the temperature for May was just the same as this month, while in 1897 it was 56.3° and in 1907, 54.5°. The weather was cold continuously during the first two weeks and again from the 22d to the 30th, the daily temperatures averaging from 10° to 20° below the normal during much of the time. Frost occurred in the northern and middle counties on the 3d, 8th, 9th, 10th and 14th; in the southern counties on the 10th and 14th, and in scattered localities on the 1st, 2d, 11th, 12th, 24th and 26th. On the 3d, 10th, and 14th the frost was quite severe, and freezing temperatures or lower were recorded on the 10th in the extreme southern counties. Considerable damage was done to early truck crops and other tender plants by these frosts, especially in the middle and southern portions of the State.

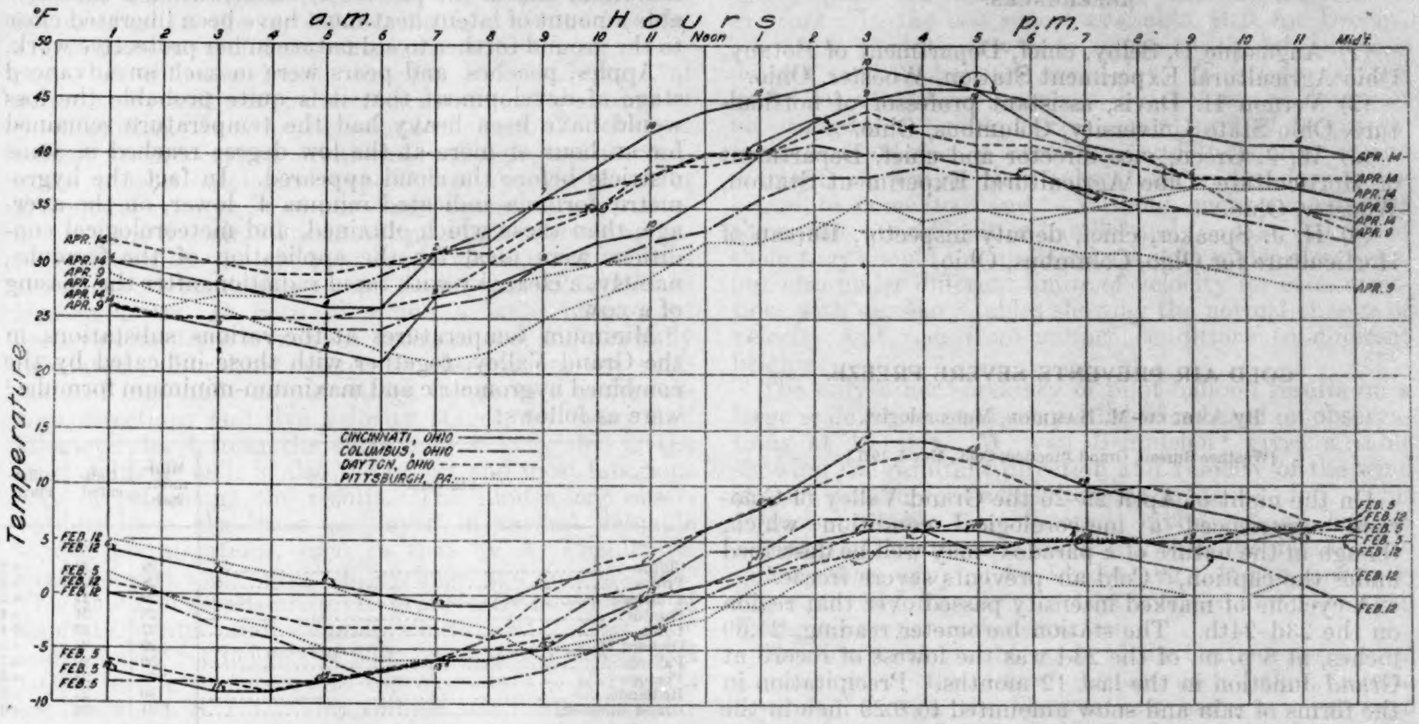


FIG. 3.—Hourly temperatures and bihourly wind velocities at Cincinnati and hourly temperature at Dayton, Columbus, and Pittsburgh, Feb. 5 and 12, and Apr. 9 and 14, 1917.

These unusually severe conditions for May occurred at about the critical period in the development of the fruit buds.

From the foregoing we are inclined to the opinion that the fatal injury to the fruit crop of 1917 in this State occurred either as the result of low temperatures on February 5, 1917, or the cool, wet weather during the period of pollinization in May. Although the temperatures experienced in February (5th and 11th) were not low enough to kill fully dormant peach or apple buds, the effect of the high winds and the unfavorable summer and autumn weather probably more than made up for any lack of sufficient coldness. The damage made by low temperatures appears to be largely owing to evaporation of moisture which can not be replaced while the buds are so cold. We are disposed, however, to attribute a large part, perhaps a major part, of the damage to May weather conditions at the critical period of pollinization.

REFERENCES.

(1) Augustine D. Selby, chief, Department of Botany, Ohio Agricultural Experiment Station, Wooster, Ohio.

(2) Vernon H. Davis, assistant professor of horticulture, Ohio State University, Columbus, Ohio.

(3) W. J. Green, vice director and chief, Department of Horticulture, Ohio Agricultural Experiment Station, Wooster, Ohio.

(4) H. J. Speaker, chief, deputy inspector, Bureau of Horticulture for Ohio, Columbus, Ohio.

COLD AIR PREVENTS SEVERE FREEZE.

By ANDREW M. HAMRICK, Meteorologist.

[Weather Bureau, Grand Junction, Colo., May 5, 1921.]

On the night of April 25–26 the Grand Valley of Colorado experienced a meteorological condition which, though in the nature of a paradox, may well be described under the caption, "Cold air prevents severe freeze."

A cyclone of marked intensity passed over that region on the 23d–24th. The station barometer reading, 24.69 inches, at 8 p. m. of the 23d was the lowest of record at Grand Junction in the last 12 months. Precipitation in the forms of rain and snow amounted to 0.29 inch in the city, which is more than one-third of the normal amount for the entire month. In the outlying fruit districts it was heavier, especially in the vicinity of Palisade, where several inches of moist snow covered the ground and a considerable amount hung on the fruit trees on the morning of the 24th.

During the cold season precipitation seldom occurs in the Grand Valley while the barometer is falling, but just after the turn upward, if the mercury has fallen to 25 inches or lower, precipitation is likely to begin and continue intermittently until it again approaches 25.50 inches. Although not a fixed rule, the precipitation is not continuous for many hours at a time, and the showers or flurries can be associated usually with small but sharp rises in the barometer.

Such conditions prevailed in the Grand Valley from 9:30 p. m. of the 23d until about noon of the 25th. At the latter hour the pressure was 25.33 inches. As the barometer was rising steadily, and local signs and the weather map indicated clearing, with the usual low temperatures caused by radiation on clear nights following storms of that character, grave apprehension concerning the fruit crop in the valley prevailed.

Clearing took place as indicated shortly after sunset, and the sky remained practically clear until about 4 a. m. of the 26th. Radiation was rapid, and the temperature fell from 47° at 6 p. m. of the 25th to 31° at about 4:30 a. m. of the 26th.

The wind was blowing steadily from the east from 1 a. m. until 3:30 a. m., when it switched abruptly to the northwest. In the springtime northwesterly winds carry colder air into the Grand Valley than do winds from any other direction. With the change in wind direction the temperature fall increased rapidly, and it soon passed below freezing.

Since there was a large amount of moisture in the valley, the relative humidity was probably quite high, and the rapidly falling temperature reached the dew point in a short while. Condensation took place in the form of a low stratus cloud, closely resembling a fog, and the latter moved rapidly across the valley from the NW. between the hours of 4 and 4:30 a. m. The cloud checked radiation, and in the process of condensation a considerable amount of latent heat must have been liberated close to the ground further to aid nature in her protective work.

Apples, peaches, and pears were in such an advanced stage of development that it is quite probable the loss would have been heavy had the temperature remained for an hour or more at the low degree reached in some districts before the cloud appeared. In fact, the hygrometric formulæ indicated minima 4° lower, on the average, than those which obtained, and meteorological conditions were ideal for the application of the formulæ, namely, a clear sky with rapid radiation, after the passing of a LOW.

Minimum temperatures at the various substations in the Grand Valley, together with those indicated by the combined hygrometric and maximum-minimum formulæ [1] were as follows:

Stations.	Minimum, 26th.	Indicated.	Difference.
	°	°	°
Clifton	29	27	+2
Fruita	28	23	+5
Fruitvale	29	24	+5
Hunter	28	24	+4
Loma	27	23	+4
Orchard Mesa	29	24	+5
Palisade	30	29	+1
Pomona	28	23	+5
Redlands	30	27	+3
Grand Junction	31	28	+3

On the following night, with practically the same weather indications, the formulæ indicated minima as follows; no cloud overspread the valley during the morning hours, and minimum temperatures were very close to the predicted:

Stations.	Minimum, 27th.	Indicated.	Difference.
	°	°	°
Clifton	28	29	−1
Fruita	25	25	0
Fruitvale	28	25	+3
Hunter	26	25	+1
Loma	24	25	−1
Orchard Mesa	29	26	+3
Palisade	31	31	0
Pomona	26	24	+2
Redlands	27	28	−1
Grand Junction	31	31	0

NOTE.—Weather maps for the two dates were quite similar, but insolation on the 26th gave higher maxima than occurred on the 25th, and the higher maxima when used in the formula indicated slightly higher minima for the 27th.

[1] See MO. WEATHER REV., Suppl. 16, 1919.

At 6 a. m. on the 26th the relative humidity was 90 per cent, the air temperature 32°, and the dew-point 30° on the roof of the Federal building in Grand Junction. Temperatures near the ground usually run 3° or 4° lower.

As it was probable that peaches, in their advanced stage of development, could not withstand dry air temperatures much below 31°, smudges were lighted in the Palisade district, but they were extinguished when the more effective natural heat preserver made its appearance.

The cloud moved in from the NW. and increased in size as it progressed, thus affording protection to all districts.

The thermogram clearly indicates the arrival of the cold NW. wind at 3:30 a. m., and the barogram shows increased pressure just after the aqueous vapor was condensed and its place filled with colder and drier air.

MAPPING THE OCEAN OF AIR.

By C. E. P. BROOKS.

[Meteorological Office, London, England, Nov. 8, 1920.]

The development of flying, and especially the establishment, actual or proposed, of various commercial flying services, involves an urgent call upon meteorologists to do that service for aviators which they have already done for seamen, namely, to chart the wind currents, in this case not for the surface only but also for the free air. The obvious way of doing this is to study the air movements at different levels directly, by the reports of aviators, by kite and balloon ascents and by studies of cloud motion. It is to the second of these, the kite and balloon ascents carried out at various aerological observatories and on aerological expeditions, that we must at present refer for most of our direct records of air movement in the free air. The most important of the observatories for which the observations have been summarized are those at Lindenberg near Berlin and Blue Hill in Massachusetts, at both of which a large number of observations have now been accumulated and partially tabulated.[1] For Lindenberg the observations are summarized seasonally as percentage frequencies under sixteen directions and five velocity stages, for every half kilometer level from the surface to 4 km.; this is the most valuable as it is also the fullest and most laborious way of presenting the results. The Lindenberg observations have also been employed in several valuable special investigations, such as that by A. Peppler on wind velocity and "veer" in cyclones and anticyclones.[2] The Blue Hill results are given graphically in the form of separate winter and summer wind-roses of frequency and velocity for heights of 650, 1,650, 3,300, 6,600, and 10,000 feet (i. e. surface and approximately ½, 1, 2, and 3 km. above M. S. L.). This volume also contains similar wind-roses for the trade wind region of the Atlantic Ocean, based on observations by Teisserenc de Bort and Lawrence Rotch on board ship[3] and another chart of considerable historic interest, illustrating aerial routes across the Atlantic eastward and westward, for an airship with an engine speed of 25 miles per hour. Observations with kites are now being taken regularly at several stations in North America and published as supplements to the MONTHLY WEATHER REVIEW.[4] J. Rouch[5] gives frequency wind-roses, with indications of force, up to 6 km. at Paris, and at 1 and 2 km. for various points in the western Mediterranean. Unfortunately these diagrams refer only to summer means, and their meaning is not made clear in the text.

The Italian Aerological Service has developed into a very active organization, publishing a *Bollettino Aerologico*, which gives in the form of a daily report tables and charts of the wind up to 5,000 meters obtained by the use of pilot balloons, with other data of interest to aviators. In the last report available, that for December, 1918, 63 stations were in operation, though all these did not send up balloons every day. This form is very useful for day-to-day purposes, but before the data can be utilized for "pilot charts" some form of frequency table or wind-rose is necessary, and it is only at the moment of writing that tabulations in this form have begun to come to hand.[6] Without such summarizing the results are difficult to handle, and to make full use of them they should be tabulated not only under directions, but also under different limits of velocity for each direction, with auxiliary tables showing the normal change of velocity and veer from surface conditions to different heights.

The only other summary of pilot-balloon results on a large scale which has been published is based on observations at Batavia. W. van Bemmelen[7] gives a table showing the resultant direction and velocity of the wind in each month for each kilometer up to 24 km. This form is valuable for theoretical investigations, but for aeronautical purposes is less useful than the detailed frequency form adopted for Lindenberg. It can, however, be employed for finding the best levels to make for when flying in any particular direction.

Mention must also be made of the German aerological expedition to the Indian Ocean and Lake Victoria Nyanza,[8] though the observations have not yet been tabulated into a form suitable for free-air wind-roses.

Of great importance also is the long series of autographic records, commencing in 1890, at the summit of the Eiffel Tower in Paris,[9] at approximately 1,000 feet above the ground, but similar direct observations are not likely to be available elsewhere or at greater heights except on mountains, where there is always the probability of local disturbance of the general conditions.

As regards the observation of cloud movements mention must be made of the researches of Hildebrandsson,[10] but these deal chiefly with the highest cloud levels and have only limited applications to aviation at present. Summaries of the directions of motion of clouds at various levels are made in many climatological discussions; these results, however, have a certain disadvantage compared

[1] For Lindenberg see e. g. Assmann R: *Die Winde in Deutschland, Braunschweig*, 1910. For Blue Hill, Rotch; A. Lawrence and Andrew H. Palmer: *Charts of the atmosphere or aeronauts and aviators*, New York, 1911.

[2] Peppler, A.: Windgeschwindigkeiten und- Drehungen in Zyclonen und Antizyclonen, *Beitr. Phys. frei Atmosph.*, Leipzig, 1912, **4**, p. 91.

[3] *Travaux scientifiques de l'Observatoire de Météorologie dynamique de Trappes.* Tome 4. Étude de l'atmosphère marine par sondages aériens, Atlantique moyen et région intertropicale. Paris, 1909.

[4] Owing to the extension of aerological work in the Weather Bureau, there has now accumulated a very large mass of observational data, both from kites and pilot balloons, the discussion of which will probably represent the best information on the upper air over the United States. Such a discussion is now in preparation.—EDITOR.

[5] *Préparation météorologique des voyages aériens.* Paris. Masson & Cie, 1920.

[6] Gamba, P. Risultsti dei lanci di palloni-sonde e palloni-piloti effettuati nel R., Osservatorio Geofisico di Pavia nel 1909, . . . 1910, . . . 1911, . . . 1912. Roma *Ann. Uff. centr. meteor. geodin.*, 1911, **33**, 176; 1912, **34**, 160; 1913, **35**, 112; 1914, **36**, 156.

[7] The atmospheric circulation above Australasia according to the pilot-balloon observations made at Batavia. Amsterdam, *Proc. K. Akad. Wetensch*, **20**, 1919, p. 1313.

[8] Lindenberg, *K. Preuss. Aeronaut. Observatorium.* Bericht über die aerologische Expedition nach Ostafrika im Jahre 1908.

[9] Angot, A.: Etudes sur le climat de la France. Régime des vents. Paris, *Ann. Bur. Centr. Météor.*, 1907, pt. 1, p. 76.

[10] Hildebrandsson, H. H.: *Résultats des recherches empiriques sur les mouvements généraux de l'atmosphère.* Upsala, 1918. (Translation in MO. WEATHER REV., June, 1919, 47:374-389; discussion by W. R. Gregg, ibid, September, 1919, 47:649-650.)

with pilot balloons, because the latter refer to the best flying weather and the former to conditions more or less disadvantageous.

There is no doubt that as pilot-balloon observations are multiplied frequency and velocity wind-roses for various levels in the free air will be constructed for other stations, but the data available are at present scanty, and several years must elapse before sufficient observations exist for reliable direct results at a network of stations.

An alternative method, which though indirect is at present much more feasible, is based on the theoretical study of the relations of wind force to pressure gradient. A synchronous pressure chart at mean sea level corresponds to a certain actual distribution of surface winds; it also represents by the direction and closeness of the isobars the "geostrophic" wind, which is what the wind would be were there no surface friction. In practice it is found that the theoretical wind based on the measurement of the isobars at sea level gives a good approximation—when numerous observations are considered—to the actual wind prevailing at a height of between 1,000 and 2,000 feet. Hence by measuring the gradient on a series of daily weather charts we can obtain tables or charts showing the frequency of geostrophic winds of different directions and velocities, and we may assume that these represent conditions at, say, 1,500 feet above ground.

Such a study of the geostrophic winds over London based on the 35 years, 1881–1915, of over 1,000 observations for each month, is published month by month in the *Meteorological Magazine*, and a similar study of the geostrophic winds over the North Atlantic is in progress, and the data have appeared in part on the pilot charts for that ocean. But much more than this needs to be done. The geostrophic winds need to be tabulated, not for isolated stations, but for a connected network of selected points. With a sufficiently close network the relationships of the geostrophic winds to geography and configuration can be made out and interpolation for any desired point will present no difficulty.

This program is perfectly feasible for the greater part of the northern hemisphere, including Egypt and India, also for Australia and the Argentine, but the work is laborious, as to provide a sufficient basis the daily weather charts for at least 10 years have to be examined and measured, and for its satisfactory accomplishment longer periods should be utilized so that international cooperation is advisable.

Two points must be remembered in connection with these pressure maps. The first is that as the air becomes less dense with increasing height, a definite barometric gradient causes winds with a proportionally greater velocity. The second is that the wind velocity corresponding to a definite gradient increases as the latitude decreases, until close to the Equator any measurable gradient at all causes theoretically infinite velocities, so that the calculation of gradient winds becomes impossible and between the latitudes of 20° north and south we must at present rely for our knowledge of the upper winds on direct observation and not on calculation.

Similar in principle, but far less laborious in practice, is the process of obtaining the *resultant* geostrophic wind. This is the result which would be obtained by averaging a large number of individual geostrophic winds at any place, the east winds being treated as negative west winds and the north winds as negative south winds. Practically the same result is obtained by measuring the average barometric gradient from a chart of mean pressure distribution. For the wind at a height of 1,000 or 1,500 feet it suffices to use a *good* detailed chart of the pressure at mean sea level, in which the isobars should be drawn for every millibar or millimeter on a projection which gives a reasonably uniform scale for different latitudes and longitudes. But for greater altitudes it is necessary to take into account the temperature of the air. For cold air is heavier than warm air, and hence in a column of cold air, pressure (i. e., weight of the overlying column of air) decreases more rapidly upwards than a column of warm air. For this reason pressure lapse with height is more rapid in higher than in lower latitudes, so that at a height of several kilometers there is in temperate and subtropical latitudes a well-marked poleward pressure gradient, causing the great preponderance of westerly winds at these levels.

Now it is found that except in very cold regions there is on the average a fairly uniform decrease of temperature from the surface upwards, amounting to about 6a per kilometer. On this basis, given a chart of the average distribution of pressure and temperature over any portion of the earth's surface, we may proceed to work upwards, calculating the pressure distribution at 1, 2, 3 kilometers, and so on, with reasonable accuracy up to 5 kilometers (16,000 feet), which is as a rule as high a level as aviators are likely to require for some time to come.

This process was first carried out by Teisserenc de Bort in connection with a study of the circulation of the atmosphere. He published charts showing the calculated isobars in January and July at a height of 4 kilometers,[11] and showed that they agreed well with the average direction of motion of cirrus clouds, though the latter are in general at a much higher level. No similar charts for the whole world have yet been published, but Col. H. G. Lyons has prepared [12] charts of the pressure distribution over the Mediterranean during January, April, July, and October at the 1, 2, 3, and 4 kilometer levels, and recently H. U. Sverdrup [13] has published mean annual maps of the eastern north Atlantic showing the topography of the isobaric surfaces of 1,000 mb., 900 mb., and so on up 300 mb. The latter form is unsuitable for the purposes of aviation but could be converted to the more usual form with little difficulty.

Thus we see that a good beginning has been made both along lines of research in the direct observation of kites and pilot balloons and in the study of geostrophic winds at various levels. The general lines of the atmospheric circulation are already charted and we have now to look forward to the gradual filling in of details, until we can construct charts with first hundreds and then a thousand or more of arrows representing the winds at various levels all over the world.

DISCUSSION.

By C. Le Roy Meisinger.

While the paper above is very interesting in the suggestions it makes for researches which may be applied to the benefit of aviation in all parts of the world, it should be strongly emphasized that averages of the meteoro-

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[11] Hildebrandsson, H. H., and L. Teisserenc de Bort.: *Les Bases de la météorologie dynamique.* Tome 2, p. 214.

[12] Monthly Meteorological Charts of Mediterranean Basin, M. O. 224, 2 ed. Introductory Sheet.

[13] Sverdrup, H. U.: Der nordatlantische Passat. *Veröff. Geophys. Inst. Univ.* Leipzig, Bd. 2, H. 1. Leipzig, 1917.

logical elements are extremely limited in their application. There is no denying the value of charts of the prevailing winds, and other auxiliary charts, in such undertakings as the preliminary laying out of air routes; but where the line of demarcation comes between climatological data and current conditions, there is indeed need to proceed with caution. The "ocean of air," as the author of the paper and others have chosen to call it, is a questionable figure of speech, because there is really very little in common in the characteristics of the aerial and aqueous oceans. Popular writers and lecturers convey the impression that there are great permanent currents sweeping through the atmosphere with the same incessant flow as the Gulf Stream or the Japan Current; the ideas thus conveyed are erroneous, for we know that, to altitudes within which flying will always be confined, there are no such streams or currents which are dependable at all times.

For that reason, it is believed that too much emphasis has been laid on the work of Rotch and Palmer, which the author mentions. True, this was the pioneer work, and as such it should be, and is, respected. But to-day there is a great deal more information upon which to base conclusions. Instead of Blue Hill and Lindenburg Observatories being the "most important" in collecting aerological data it is now to be remembered that the Blue Hill Observatory has not been making upper-air soundings for several years; hereas, the Weather Bureau is maintaining at the present time six kite stations which make frequent kite and pilot-balloon ascensions, and in addition, including aerological stations of the Army and Navy which cooperate with the Weather Bureau, there are 21, and during the hurricane season 24, pilot-balloon stations. It is evident that, with such activity, an immense amount of data has been compiled and is constantly being added to.

It should be recalled, also, in this connection, that the network of aerological stations in Europe at the present time is much closer than that in the United States, owing to the smaller sizes of the countries, and the consequently shorter distances between stations. For example, in Italy alone there are 30 aerological stations whose wind data to the height of 5,000 meters have been published for a long time.

The deduction of the resultant movement of the air from mean-pressure distribution upon the principle of the gradient wind would seem to be of greater value in discussing the general circulation of the atmosphere during certain periods than in conveying to the aviator an impression of the wind movement aloft. Charts and tables of the geostrophic wind, such as those published in the *Meteorological Magazine*, would, however, be of unquestioned value in determining the wind frequencies aloft. There would be other charts of a statistical nature which could be profitably used, such as those showing frequencies of winds above certain limiting speeds, or characteristic turning with altitude under different typical distributions of pressure and temperature at the surface. These would not only aid the aviator, but would perhaps assist the trained meteorologist even more in forming his judgment of probable conditions aloft, when he is unable to get current data.

But above all, in any discussion of such information as Mr. Brooks has suggested in his paper, the aviator, who is the ultimate consumer, must be warned very carefully indeed lest he misinterpret the significance of averages. He is very likely never to find the conditions aloft which his chart of prevailing winds shows; and if he does not realize this, he may not only be unpleasantly surprised in flight, but may be inclined to lose the respect and confidence which he may previously have had for the meteorologist who is trying to assist him.

The paper was actually suggested during the compilation of a bibliography of upper-air data, when it was thought that some account of the lines along which the available material was being utilized would be of interest. As the bibliography already included well over 100 cards, it was obviously impossible to deal with each separately, and the references were accordingly limited to data which had been summarized in a way presenting features of interest. At the time no summary of the data in the admirable Italian *Bollettino Aerologico* was known, but recently several discussions by Gamba have come to hand and references to them have been added.

I quite agree that the only good form of summary is one in which the direction frequencies are subdivided into velocity frequencies, but when this is done they are at least as useful as corresponding wind-roses over the sea surface, which are published in marine "pilot charts" and are readily understood by seamen. Such tables for the air over North America or Europe indicate that the aerial currents are variable (as are the marine currents in many parts of the ocean); in other places, as in the Trades or in southwest Asia, the air currents at certain levels have an extraordinary constancy, quite on a par with that of the great ocean currents.—*C. E. P. B.*

PROGRESS IN MAKING FREE-AIR PRESSURE AND WIND CHARTS.[1]

By C. LeRoy Meisinger.

[Weather Bureau, Washington, D. C., Apr. 20, 1921.]

SYNOPSIS.

This study, which has been outlined in earlier papers, has been carried forward so that it now includes the results from all kite flights made at about 8 a. m., at all the aerological stations of the Weather Bureau, up to the end of 1920. Smoothed tables of differences between the mean temperature of the air column and the surface temperature, under different conditions of surface wind, have been constructed for each month from isopleths which were drawn from the original data. These smoothed tables have been modified to include the effect of vapor pressure. With such tables it is possible to draw free-air maps of the eastern United States for each month according to the surface wind direction, and, from the maps, to interpolate for any other station. A comparison of observed and computed pressures at the 1 and 2 kilometer elevations above sea-level in 20 kite flights selected at random after January 1, 1921, indicates that the method will probably be of sufficient accuracy to be useful.

In previous papers[2] a method has been outlined by means of which it is proposed to reduce barometric pressure to levels in the free air. The central idea of the method is that surface wind directions are an index to temperatures aloft. Such temperatures must be known in order to substitute correct numerical values in the hypsometric formula for the term representing the mean temperature of the air column. The plan of the investigation has been, therefore, to classify for each month, according to surface wind direction, the differences between surface temperature and the mean temperatures of the air columns between the surface and the 1- and 2-kilometer elevations above sea level. These differences have been determined from all the kite flights made at about 8 a. m. at the Weather Bureau aerological stations up to the end of 1920, comprising about 4,000 observations to the 1-kilometer level, and above 3,000 observations to the 2-kilometer level. For each of the seven aerological stations, isopleths, or diagrams in which months are plotted as abscissae and wind directions as ordinates and which show lines of equal temperature difference were constructed; and from them in turn tables of smoothed temperature differences were made. Examples of such isopleths were given in the Review for May, 1920 (p. 257), although those there presented have since been modified by the inclusion of more data.

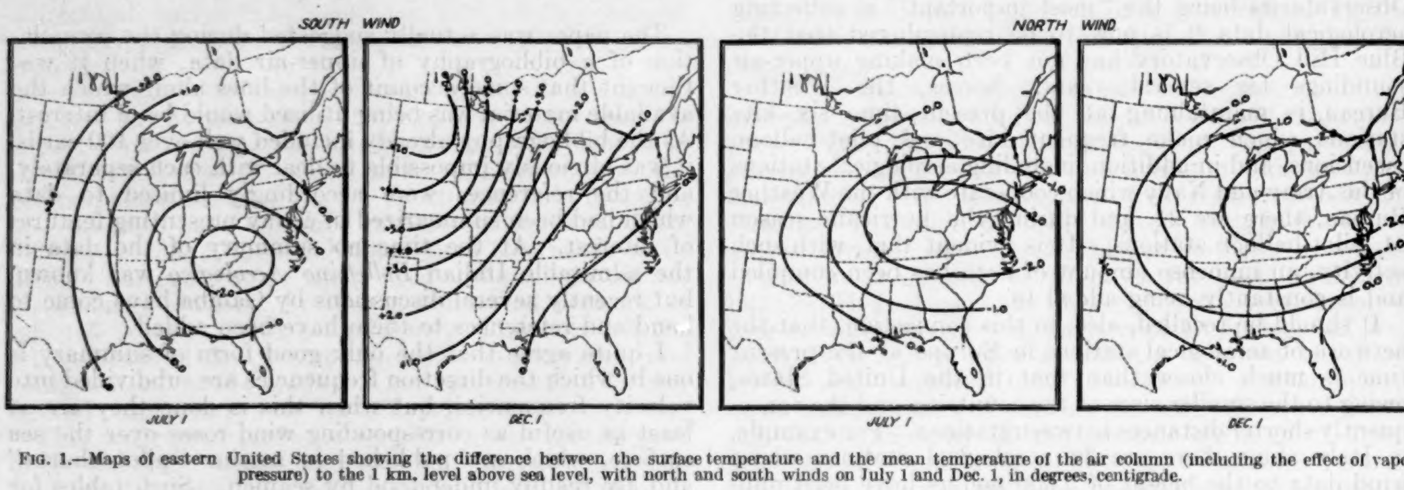

Fig. 1.—Maps of eastern United States showing the difference between the surface temperature and the mean temperature of the air column (including the effect of vapor pressure) to the 1 km. level above sea level, with north and south winds on July 1 and Dec. 1, in degrees, centigrade.

Of the variables in the hypsometric formula, that representing vapor pressure is second only to the variable representing the mean temperature of the air column in its effect upon the reduced pressure. Consequently, in order to include adequately the effect of this term, small values of temperature, which were equivalent to the corresponding effect of vapor pressure, were added to each of the values in the tables obtained from the isopleths. The values of vapor pressure were obtained from the summary of aerological data now in preparation in the Aerological Division of the Weather Bureau, and are the mean monthly values. Thus, from tables showing the differences of temperature between the 1- and 2-kilometer levels and the surface and including the effect of vapor pressure, values were plotted on maps of the eastern United States and lines of equal difference drawn. Figure 1 shows such maps, the first being for south winds at all stations on July 1; the second for south winds at all stations on December 1; the third and fourth for north winds on the corresponding dates. The effect of coastal and continental conditions is evidenced by the smooth progression from a temperature inversion, even in summer, in the interior to a decrease of temperature with height along the eastern coast, even in winter, with all surface wind directions. These results are exactly what one might expect, and the very easy transition from one map to the next, when many are arranged in order, together with the smoothness with which the values distribute themselves, indicates that the probable accuracy is satisfactory. This was also indicated by a statistical study of the errors in an earlier paper. From these maps it will be possible to construct reduction tables for most of the eastern United States, and, after considerable laborious tabulation, to draw daily upper-air maps.

[1] Presented before the American Meteorological Society, at Washington, D. C., Apr. 20, 1921.

[2] Cf. *Bulletin of the American Meteorological Society*, Jan., 1920, p. 8; May, 1920, p. 53; also Mo. Weather Rev., May, 1920, pp. 251-263. The essential features of the method were also mentioned in *Science*, Oct. 29, 1920, pp. 411, 412.

TABLE 1.—*Comparison of observed and computed pressures at upper levels.*

Station.	Date.	Surface.		Pressure aloft.					
				1-km. level.			2-km. level.		
		Wind dir.	Pressure.	Obsd.	Cmptd.	Diff.	Obsd.	Cmptd.	Diff.
	1921.		*mb.*	*mb.*	*mb.*	*mb.*	*mb.*	*mb.*	*mb.*
Groesbeck, Tex..	Jan. 13	NW...	1,000.7	898.9	899.0	0.1	794.1	792.7	−1.4
	Jan. 21	SE....	1,007.7	910.4	911.3	0.9	808.3	810.1	1.8
	Feb. 10	NW...	998.9	899.6	899.5	−0.1	795.4	795.1	−0.3
	Feb. 18	E.....	1,005.2	905.1	904.6	−0.5	800.9	800.1	−0.8
Broken Arrow, Okla.	Jan. 1	W.....	985.3	896.5	896.2	−0.3	792.5	791.9	−0.6
	Jan. 27	S......	999.9	907.7	908.9	1.2	803.9	801.2	−2.7
	Feb. 10	NW...	985.4	896.0	895.7	−0.3	791.7	791.9	0.2
	Feb. 21	S......	989.8	899.1	898.9	−0.2	793.1	792.1	−1.0
Ellendale, N. Dak.	Jan. 8	W....	970.6	901.8	902.8	1.0	792.1	794.1	2.0
	Jan. 24	NE...	978.0	909.6	909.7	0.1	800.5	799.4	−1.1
	Feb. 8	SW...	956.5	891.0	890.0	−1.0	784.9	780.2	−4.7
	Feb. 27	SW...	956.5	893.0	891.4	−1.6	789.6	786.4	−3.2
Drexel, Nebr....	Jan. 2	SW...	962.1	892.2	891.9	−0.3	787.4	787.2	−0.2
	Jan. 7	N.....	968.9	898.4	898.4	0.0	792.1	793.7	1.6
	Feb. 7	N.....	977.3	904.1	902.7	−1.4	794.2	792.3	−1.9
	Feb. 14	E.....	973.3	904.4	903.1	−1.3	802.1	802.1	0.0
Royal Center, Ind.	Jan. 5	NW...	990.6	898.0	898.7	0.7	792.0	792.5	0.5
	Jan. 6	SE....	998.3	906.6	906.5	−0.1	802.3	800.8	1.5
	Feb. 2	SW...	991.7	899.3	899.5	0.2	790.0	792.1	2.1
	Feb. 14	NE...	994.2	904.1	903.5	−0.6	800.2	799.1	−1.1
Mean difference						0.5			1.4

As a test of the method, 20 comparisons were made for each of the two levels at each of the active kite stations (see Table 1), and it was found that, for the 1-kilometer level, the differences between computed and observed [3] values were 1 mb. or less in 16 cases, the remaining 4 not exceeding 1.6 mb. For the 2-kilometer level, where, of course, larger discrepancies were to be expected as a result of the long reduction column, 8 cases gave differences of 1 mb. or less; 16 were below 2 mb.; 18 were below 3 mb.; and the remaining 2 were 3.2 and 4.7 mb., respectively. The mean difference was 0.5 mb. for the 1-kilometer level and 1.4 mb. for the 2-kilometer level. A further careful discussion of the results and some trial upper-air maps will be made. The work seems to hold promise of being of considerable value to aviation, and it is hoped will be of subsequent value in attacking the problem of Plateau barometry.

METEOROLOGY IN THE SERVICE OF AVIATION.

By G. DOBSON.

[Abstracted from *Aeronautics*, Feb. 17, 1921, pp. 113-116; published in greater detail in *The Aeronautical Journal*, May, 1921, pp. 223-238.]

The well-known problems confronting the aeronautical meteorologist are discussed with special reference to England. The information most needed is, first, with respect to the variation of speed and direction of wind with height; second, the heights of cloud bases and the thickness of the layers; third, warnings in case clouds come so near the surface as to make landings dangerous; and, fourth, the nature of the weather likely to be encountered along the route, with special attention to squalls or other local disturbances. After discussing the various means of obtaining these data, the author inclines to the belief that the best results will come from locating meteorological stations along the routes, and having these stations report their weather and upper-air data obtained from frequent kite-balloon ascensions, assuming the conditions between observations to remain the same as at observation. He admits, of course, the value of widespread aerological stations, but rules them out for financial reasons. The danger of having kite-balloon cables in the air near flying routes is disposed of by having the meteorological stations as much as 30 to 50 miles either side of the route. Communication from these stations should be by wireless.

The methods of dispersing fog over small areas, namely, heating, blowing powdered calcium chloride into the air, and electrical discharge, are discussed and negative conclusions drawn. Heating the air with coal heaters would not yield sufficient heat and would add nuclei of condensation to the air. Spraying powdered calcium chloride into the air would tend to collect the water out of the air about the particles until they would be so heavy as to fall. This would require great quantities of the powder, but would give the greatest promise of any of the methods. The method of dispersing fog in the laboratory by means of the brush discharge would have an inconsiderable effect in the open air. Moreover, if any method for dispersing or precipitating fog were practicable, the quantity of water which would result would be considerable.

The author concludes his paper by the expression of mild pessimism regarding the ability of the meteorologist at present to give the aviator just what he wants, although the importance of meteorology in aviation is denied by none.

The paper was discussed by Col. Gold, Maj. Gen. W. S. Brancker, Col. W. D. Beatty, and Maj. H. G. Brackley. The trend of opinion among those who talked was that too little importance had been attached to the value of forecasts and too much to the assumption that frequent observations along a single route would be satisfactory. The distance of 30 to 50 miles from observing station to the route would be too great, but to put kite balloons closer would be dangerous for airplanes flying in that vicinity. Pilots want a concise statement before they start, and should be instructed to report conditions encountered in flight.—*C. L. M.*

BRITISH AND FRENCH RADIO WEATHER SERVICE FOR AVIATORS.

(Reprinted from *Science*, Sept. 17, 1920, p. 271.)

The Air Ministry, in an official notice to airmen, according to the London *Times*, details innovations recently introduced in the dissemination of meteorological statistics and forecasts by wireless telegraphy for the use of aircraft. Reports are issued from the Croydon aerodrome on a 900-meter continuous wave each day, including Sundays, at hourly intervals between 7:35 a. m. (G. M. T.) and 4:35 p. m., the data in each consisting of observations made 35 minutes previously at the following places: Felixstowe, Croydon, Biggin Hill, Lympne, Beachy Head, Dungeness, and Botley Hill (North Downs). In addition to the usual information, the messages now include the direction and speed of the low cloud, the character of the sea swell, and the visibility toward the sea is distinguished from that over the land, the latter important feature being observed at various points along the channel coast. A statement is also added regarding the conditions prevailing on the North Downs as viewed from Biggin Hill, while at 8:25 a. m.

[3] While no study of the accuracy of the *observed* pressures has been made, it has been estimated that it does not exceed 1 mb. The probable variation of the *computed* pressures, as determined by a statistical study of the data, is about 0.5 mb. for the 1-km. level, and 1.3 mb. for the 2-km. level, values which are in close agreement with the mean difference of the 20 random cases selected above. While 20 cases are too few to base generalizations upon, it would seem that the close agreement between the probable variation of a single value of computed pressure and the mean difference between observed and computed pressure would indicate that the probable error of a single observation of pressure is less than 1 mb., as estimated above. A study of a large number of computed and observed pressures might afford an indirect, but reliable, means of determining the probable error of pressure observations by the meteorograph.

the complete results of a pilot-balloon ascent at Croydon or Lympne are appended whenever available. Every statement is suffixed by the latest Meteorological Office estimate of the probable weather during the remaining hours of daylight. Reports of a similar character are also issued on the same wave length from Le Bourget seven times daily, the observations transmitted in this case being derived from St. Inglevert, Abbeville, Maubeuge, Havre, and Le Bourget.[1]

HIGH-ALTITUDE METEOROLOGICAL SERVICE BY WIRELESS.

(Reprinted from *Aeronautics*, London, Apr. 21, 1921, p. 285.)

Meteorological bulletins for aeronautical purposes, prepared by the High-Altitude Meteorological Department of the Prussian Aeronautical Observatory at Lindenberg, are now spread by wireless from the Königswusterhausen Radio Central Station by a 3,200-meter wave (undamped) at the following times: 6:50–7 a. m., 10:40–10:50 a. m., 5–5:10 p. m.. 9:15–9:25 p. m. Each of these bulletins comprises: (1) A résumé of high-altitude data as derived from pilot- and captive-balloon ascents as well as airplane observations, and expressed in a special code; (2) a summary of barometer readings over the whole of Europe; (3) weather bulletins for Central Europe; (4) a prognosis for Central Europe, special regard being taken to the requirements of aeronautics.—*A. G.*

DISTRIBUTION OF WEATHER INFORMATION, FORECASTS AND WARNINGS BY NAVAL RADIO FOR THE BENEFIT OF AVIATION AND MARINE INTERESTS.

In cooperation with the Office of Communications of the Navy Department, the U. S. Weather Bureau will issue a special bulletin containing surface weather observations from regular Weather Bureau stations, upper air observations from aerological stations maintained by the Navy, Army, and Weather Bureau, and a summary of weather conditions, forecasts, and warnings. The bulletin is for the benefit of marine and aviation interests, but is designed especially to meet the needs of the latter. The bulletin will begin June 1, 1921, and will be broadcast from the naval radio station at Arlington, Va., each morning at 10:30 o'clock (75th meridian time), Sundays and holidays included. This service is in addition to the distribution now being made each night from the naval radio stations at Arlington, Va.; Key West, Fla.; Point Isabel, Tex.; Great Lakes, Ill.; and San Juan, P. R., as described in Weather Bureau circular of October 26, 1920.

Full details of this new service, including code used, may be obtained by addressing the Chief of the U. S. Weather Bureau, Washington, D. C.

Beginning June 10, 1921, in cooperation with Office of Communications of the Navy Department, there will be a systematic broadcasting of wind and weather forecasts, storm and hurricane warnings, and advices relating thereto from naval radio stations on the south Atlantic and Gulf coasts, in the Caribbean Sea, and on the Great Lakes. This distribution will be in the nature of a localized service, and supplemental to the general broadcasting of weather forecasts, warnings, and bulletins from the high-powered naval radio stations at Arlington, Va.; Key West, Fla,; San Juan, P. R.; Point Isabel, Tex.; and Great Lakes, Ill., as described in Weather Bureau circulars of October 26, 1920, and May 16, 1921.

Whenever storm or hurricane warnings are issued in the forenoon (based on 8 a. m. observations), they will be broadcast at the same time as the wind and weather forecasts. When issued in the afternoon (based on special observations), they will be broadcast at the evening hours indicated.

Vessel owners and others desiring to receive these reports should make every effort to obtain them on regular schedules, as repetitions, except as indicated, will be made only in unusual circumstances.

A circular, containing a table showing the naval radio stations which will transmit forecasts, the wave-lengths employed by each station, the hours of distribution, etc., may be had upon application to the Chief of the U. S. Weather Bureau, Washington, D. C.

AIRCRAFT AND LIGHTNING.

An experienced flier discusses the possibility of airplanes in flight being struck by lightning during a storm in a recent issue of *Illustrierte Flug-Welt*. His remarks are based on some 70 flights under such circumstances and on general principles. He shows that no danger is to be expected in the first place if the machine is not in the direct line of the discharge, and in the second place, even if it is, it is not likely from the nature and distribution of the conducting metal portion that danger due to fire will arise. Out of 30 cases where the machine was struck directly, the writer maintains that there were no evil effects, while in all known cases in Germany where a machine fell during a storm there was no evidence of scorching or parts or melting of metal.—*Sci. Am.*, Feb. 12, 1921, p. 123.

Lightning struck two kite observation-balloons operating with the Atlantic Fleet off the Chesapeake capes last night. Both were destroyed, but they were not manned.—*Evening Star* (Washington, D. C.), June 9, 1920.

LIGHTNING PLAYS HAVOC WITH BALLOONS AT GUANTANAMO.

There is a balloon school, too, in which observers are taught to ascend in captive balloons—the "sausages" of the war—but Guantanamo's neighborhood seems to be dangerous to these craft. Last year three were brought down by lightning.—*Herbert Cory*, in *National Geographic Magazine*, Washington, June, 1921, p. 591.

POTENTIAL GRADIENT AND THUNDERSTORM FORECASTING.[1]

By A. HÖLZEL.

(Reprinted from *Science Abstracts*, Sect. A., December 30, 1921, §1540.)

Records of potential gradient and thunderstorms at Leipzig are examined with a view to determining whether any useful warning of the approach or formation of a thunderstorm may be obtained from observations of potential gradient. The records extend over the period January, 1913, to July, 1914, inclusive. The first dis-

[1] A British flying weather forecast (7 p. m., Aug. 15, 1920) is published in *Aviation*, etc., No . 1, 1920, p. 224.—EDITOR.

[1] Annal. d. Physik, Nov. 27, 1919, 60:521–547. Disertation, Leipzig.

turbance of the potential gradient, associated with 17 storms which passed over the station, preceded the first rain (taken as indicating the arrival of the storm) by periods ranging from 3 to 109 minutes and averaging 46 minutes. In 6 cases the rate of travel of the storm was known, the average being 33 km. per hour, yielding an average distance at the time of the first disturbance of the gradient of 33 km. Of the storms which passed at a distance from the station, some were associated with rain at the station and others not. Of the former, the first disturbance of the gradient preceded the rain by intervals ranging from 0 to 42 minutes. From the forecasting point of view, however, the first disturbance of the gradient by a thunderstorm can not be distinguished from disturbances due to minor causes. The author goes on to consider the time at which the gradient has reached a certain value as a criterion of the approach of a storm and reaches the conclusion that it is within the bounds of possibility to receive a warning of half an hour to one hour by observations of the potential gradient considered in relation to its normal course. This warning will usually precede the first thunder heard. The instruments used at Leipzig are described, and the mean diurnal variation of potential gradient for each month and the seasonal variation for the period Jan., 1913, to July, 1914, are included in the paper.—*M. A. G.*

INVESTIGATIONS ON LIGHTNING DISCHARGES AND ON THE ELECTRIC FIELD OF THUNDERSTORMS.[1]

By C. T. R. WILSON.

[Abstract of discussion at the Meteorological Office, London, by G. C. Simpson, Nov. 29, 1920; reprinted from *The Meteorological Magazine*, London, March, 1921, pp. 242-243.]

Mr. Wilson has invented very ingenious apparatus by which rapid changes in electric force near the ground are recorded, and he has obtained records which show how the electric field varies during a thunderstorm. Between two lightning flashes the change in the force is gradual, an asymptotic approach toward a limit, but when a flash occurs there is a sudden change in the field. In the flash equal positive and negative charges run together and the electric moment which is proportional to the magnitude of these charges and their distance apart can be estimated from the record. It is found that the charges are of the order of 20 coulombs. According to Mr. Wilson, the clouds may carry either negative charges above and positive below or positive above and negative below. Dr. Simpson demonstrated, however, that the new evidence was consistent with his own theory, according to which the electrification, being due to the breaking up of drops, was always negative above and positive below. He criticised with some severity an extension of Wilson's theory which purported to explain the normal fine-weather potential gradient as a by-product of thunderstorms.

In the subsequent discussion Dr. Chree explained the bearing of these researches on the growth of crops under electric stimulus. Sir Napier Shaw emphasized the desirability of obtaining simultaneous records from three or more stations during the progress of a storm.

LIGHTNING EXPLODES TREE AND DIGS TRENCHES.

On the night of December 20th, at 7:30 p. m., a thunderstorm came up from the southwest, with occasional thunder about 7:45 p. m. A vivid flash of lightning lighted up the darkness about as much as a brilliant light in a room.

A fraction of a second after the first thunderclap an explosion took place in my telephone. The report was equal to that of firing a shotgun in the room with a charge of three drachms of powder. I immediately investigated the telephone and a strong odor as of burning powder was escaping from it. I could see no damage to the phone, but it failed to operate.

On the morning after the storm I went out to look along the telephone line. Sixty-four rods west of the house I found that a tree had been struck by lightning 100 feet north of the telephone line.

The tree was about 15 or 20 inches in diameter at the ground and about 50 feet high, as near as I could estimate its height. The entire body of the tree was riven into pieces and none of it left near the place where it had been standing. About 18 feet of the top with many branches intact lay immediately over the place where the tree stood. What remained in the ground was torn

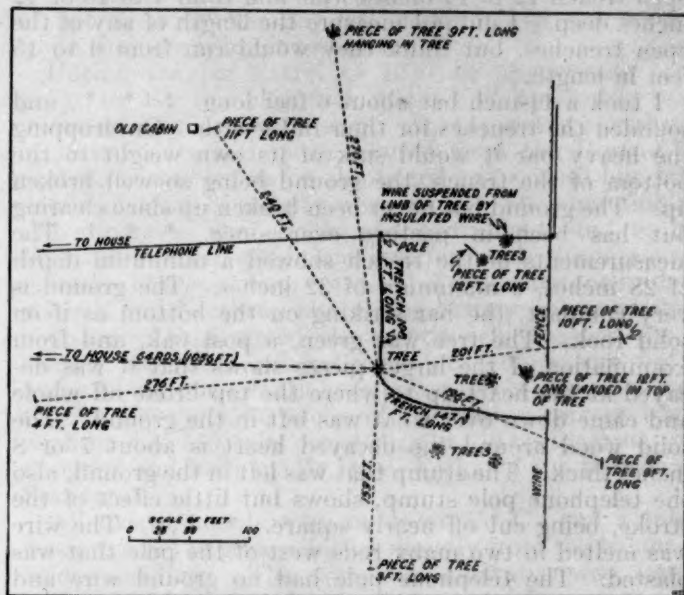

FIG. 1.—Lightning-stroke dispersion of tree-splinters and course of root trenches. (A. F. Stevens, Gravette, Ark.)

off at the surface of the ground, but was riven and shivered into slivers.

The telephone pole 100 feet south of the tree was shorn off at the top of the ground and lay some 50 feet southwest of its original position, riven into slivers.

But what surprised me most after looking over the area over which the body (of the tree) lay strewn was what I have marked "trenches" on the rude plat I am inclosing. [Fig. 1.] These start at the stump of the tree and run in directions indicated by solid lines and marked "trench." The one running south is 108 feet long, a little longer than a direct line from the stump to the telephone pole and ends abruptly at the pole with but little disturbance of the earth on the south side of the pole. What I call trench is not a clean dug trench. In places there have apparently been explosions that have thrown out much dirt; again it was heaved up like the dirt along where a mole has heaved up a runway. Some places it is widely cracked open along the middle of that portion of the earth that lies highest or is raised highest. It runs in a sinuous line as I have tried to draw it. The other trench is 147 feet long, starts out from the stump in a northerly direction, then curves to the left and takes

[1] Phil. trans. Roy. Soc. London, 1920, Ser. A, 221 : 73-115.

almost a straight line with but slight sinuosity in a west by northwest direction and ends up at the wire fence as abruptly as the south trench does at the telephone pole.

I have indicated on the plat by short, solid lines the position and length pieces of the tree, and by broken lines the direction the pieces must have taken as they were catapulted by the explosion. The largest piece of the tree body hangs to a tree northeast of the tree to which the telephone line was attached. It is about 12 feet long and perhaps 8 inches by 6 inches in diameter.

The ends of the telephone wire at the pole standing near the wire fence was apparently melted in two. Also, the wire that held the main wire to the insulator on the post was about one-half melted away and reduced in size.

What is puzzling to me is why it seems to end so abruptly at the pole and the fence, there apparently being no diminution in the electrical force in the trench which ends so abruptly. The ground along the trench is broken up about 15 or 20 inches in width with occasional open trench 12 to 14 inches wide and from 4 to 10 or 12 inches deep. I did not measure the length of any of the open trenches, but think they would run from 6 to 15 feet in length.

I took a 1¼-inch bar about 6 feet long * * * and sounded the trenches for their full length. On dropping the heavy bar it would sink of its own weight to the bottom of the trench, the ground being so well broken up. The ground has never been broken up since clearing but has been in pasture ever since. * * * The measurements of the trench showed a minimum depth of 28 inches, a maximum of 32 inches. The ground is very compact, the bar striking on the bottom as if on solid rock. The tree was green, a post oak, and from examination of the larger pieces shows that it was decayed at the heart up to where the top broke off whole and came down over what was left in the ground. The solid wood around the decayed heart is about 7 or 8 inches thick. The stump that was left in the ground, also the telephone pole stump, shows but little effect of the stroke, being cut off nearly square. * * * The wire was melted in two many rods west of the pole that was blasted. The telephone pole had no ground wire and the lower wire of the fence was 6 inches above ground. The trench running west to the fence stopped directly against the fence post in the same manner that it did at the telephone pole, but the fence post suffered no damage except to be slightly loosened in the ground. The ending of each trench at the telephone pole and fence post to all appearances ended up with about the same force, showing about the same eruptive force and the same depth, yet one was torn off and the other uninjured. In carefully looking over the ground within 100 feet of the blasted tree the ground was littered with hundreds of small bits of wood from an inch to several inches long and from one-fourth to an inch in thickness. The decayed portion looked as though it had been coarsely ground up and widely scattered.—*A. F. Stevens*, Gravette, Ark.

During a severe thunderstorm recently near Milldale, Warren County, Va., a bolt of lightning after shattering a large tree ran down into the roots and plowed furrows a foot deep for 25 feet in every direction. The bolt was so severe that many panes of glass in a near-by house were shattered, even where the outside blinds were closed.[1]

[1] From report in Washington, D. C., *Evening Star*, May 5, 1921.

UNUSUAL LIGHTNING.

By ROBERT E. HORTON.

[Voorheesville, N. Y., October, 1920.]

On the evening of Sunday, September 5, 1920, between 6 and 7 p. m., the writer observed unusual forms of lightning at his laboratory near Voorheesville, N. Y. A severe thunderstorm was approaching from the northwest. This storm came down the Mohawk Valley, passing Utica about 4 p. m. The storm clouds spread out far to the south and east from the storm itself, in apparently a nearly horizontal layer of only moderate thickness and height, but very uniform. Clear sky could be seen to the west and southwest over the Helderberg escarpment.

From the writer's position he could observe the storm approaching from a distance of many miles. Lightning bolts passed frequently from the clouds to the ground, or vice versa, in very nearly straight vertical lines. At the same time, branching forks of lightning would spread out from the point of issue of the main bolt in all directions from the place where the earth charge left or entered the clouds. Apparently most of these forked branches shot out horizontally between the east and northeast. That may, however, have been an effect of perspective. Commonly two or three horizontal branches would strike out along the under surface of the clouds, and each would subdivide sometimes into four or five minor branches, the branches traversing a horizontal angle relative to the observer of 20° or 30°, and then dying out.

On two occasions what appeared to be balls of lightning shot horizontally from the eastern to the western portion of the horizontal cloud layer, apparently traversing the under surface of the cloud. These balls of lightning were at a great distance, and as they traversed an angle relative to the observer of 30° to 45°, their distance of travel must have been several miles. Their velocity appeared to be much slower than that of lightning. They were apparently unaccompanied by thunder, and occurred intermediate between the occurrence of the other lightning flashes described.

The forked, horizontal lightning above described was observed by several persons who were with the writer at the time. Unfortunately, none of these persons happened to notice the ball lightning. The writer is certain, however, that this was not an optical illusion, especially in view of the fact that both the balls of lightning referred to disappeared as they passed behind a barn within the range of the writer's vision and then reappeared on the other side.

Mr. George T. Todd, local forecaster, of the U. S. Weather Bureau, states that he observed the same storm and noted the peculiar horizontal, branched and forked lightning, but did not see the ball lightning. He watched the storm while traveling by automobile from Gloversville to Albany during the hours 6 to 8 p. m. Herbert E. Vail, assistant, U. S. Weather Bureau, Albany, states that during the same storm he observed a ball of lightning fall and strike the ground between his house in Albany and an adjoining house.

NOTES, ABSTRACTS AND REVIEWS.

NEW DETERMINATIONS OF THE PRECIPITATION OVER THE OCEANS.

By J. VON HANN.

[Abstracted from *Petermann's Mitteilungen*, June, 1920, pp. 126-128.]

While fairly reliable determinations of total precipitation over land areas can be made, such determinations for the oceans must depend upon less direct observations. The means usually employed to arrive at this quantity consist in attributing the difference between the estimated evaporation and the estimated inflow from rivers to precipitation. This assumes, of course, that sea-level remains constant. But different investigators have arrived at widely different results. For example, Brückner, Schmidt, and Lütgens have obtained 1,052 mm., 755.6 mm., and 1,410 mm., respectively, for the value of the annual precipitation.

The wide divergence of these values has led von Kerner to make a new investigation based on the new rainfall maps of the Atlantic and Indian Oceans by Supan, and, while he has reason to believe that his value is somewhat too high, it is in very good accord with that of Brückner, namely, 1,000 mm. A short table of his values for various latitudes is given:

Latitude (°, N. and S.)	0-10	10-20	20-30	30-40	40-50	50-60	60-70
Precipitation (mm.)	1,625	875	525	1,000	1,375	1,050	550

For the whole earth, the ratio of ocean precipitation to land precipitation reaches a maximum in middle latitudes.—*C. L. M.*

ICE IN THE ARCTIC SEAS DURING 1920.

[Reprinted from *Nature*, London, Apr. 14, 1921, p. 216.]

The Danish Meteorological Institute has published the issue for 1920 of the annual report on the state of the ice in the Arctic seas. The year showed several peculiarities in amount and distribution, although information was lacking from many regions. In the Barents Sea ice was much scarcer than usual, and there was open water as far east as Novaya Zemlya all the summer, while even the Kara Sea offered fewer difficulties than in normal years. On the west coast of Spitzbergen[1] the condition differed little from the normal, but Storfjord was exceptionally free from ice in late summer. There is little information from the east coast of Greenland, but more ice than usual passed around Cape Farewell into Davis Strait. This meant that the ice must have been packed close against the east coast, since the shores of Iceland were practically free from ice throughout the year.

On the Newfoundland Banks icebergs were numerous, and drifted somewhat further south than usual during the first half of the year. In Davis Strait and Melville Bay the ice was more abundant than usual during the spring and early summer.

[1] See "Mild Winter of 1920-21 in Northern Europe," MO. WEATHER REV., Feb., 1921, 49:89.

PRACTICAL APPLICATION OF THE ELECTRICAL-CONDUCTIVITY METHOD OF MEASURING SEA-WATER SALINITY.

By A. L. THURAS.

[Reprinted from *Jour. Wash. Acad. Sciences*, vol. 11, no. 7, pp. 160-161.]

Heretofore the only reliable method of measuring the total salt content of sea water has been by chemically titrating for the amount of chlorine present. The relation of chlorine to the total salts being a constant, a measure of the salinity is thereby obtained. Salinity is defined as the number of grams of total salts in 1,000 grams of sea water. The titration method, being a laboratory method, requires that the samples after collection be stored in suitable bottles until they can be tested on shore. The disadvantages of such a method are the loss or breakage of samples, possible errors from evaporation and handling, and the great undesirability of not knowing the physical properties of the waters while they are being investigated.

During the Ice Patrol of 1920 an opportunity was given to use the electrical method of measuring sea-water salinity on board ship. An apparatus consisting of instruments and parts secured from the Bureau of Standards was set up on shipboard and several hundred determinations of salinity were made. The operation of the apparatus was simple and convenient, and at no time did weather conditions interfere with the measurements. This apparatus consisted of a Wheatstone bridge, a Leeds and Northrup alternating-current galvanometer, a specially constructed electrolytic cell designed for a salinity recorder,[1] a hand-regulated temperature bath, and a rebuilt one-twelfth horsepower direct-current motor to give 120 volts, 60 cycles of alternating current when connected to 110 volts direct current. This machine was designed and built by Mr. A. J. Fecht, of the Bureau of Standards.

All measurements were made at 25° C., and a table was prepared to give salinities directly from the balanced bridge readings. The complete apparatus was tested each day by standard sea water taken from a supply which had been carefully measured both by a chemical method and a density method[2] before beginning the cruises. This supply of sea water lasted throughout the cruises. The temperature of the electrolytic cell bath could easily be held to within 0.03° C., and the bridge, after balancing the moving coil of the galvanometer so that the center of mass was fairly near the axis of support, could be set to a value corresponding to 0.02 in salinity. No electrical capacity or inductance was necessary for balancing the bridge, and variations in the voltage and frequency of the generator had no appreciable effect on the bridge setting. With the rough apparatus used the determinations were accurate to 0.05 in salinity, or better than 0.02 of 1 per cent.

Since the electrical conductivity method may be satisfactorily used at sea to measure the salt content of ocean

[1] See *Jour. Wash. Acad. Sciences*, 1918, vol. 8, pp. 145, 680; also "An Electrical Instrument for Recording Sea-Water Salinity," by E. E. Weibel and A. L. Thuras in MO. WEATHER REV., Feb., 1919, 47:105-106.

[2] See *Jour. Wash. Acad. Sciences*, Washington, 1917, vol. 7: 605.

water, attention is directed to the references given in the footnotes which describe an apparatus which will give a continuous record of sea-water salinity from a moving vessel. This instrument in conjunction with an instrument to record temperature, which has been constructed, would give the three most important physical variables of sea water, namely, temperature, salinity, and density. Such records taken regularly over the same course would show monthly and yearly variations of these physical properties which might be of much scientific value.

ETHER DIFFERENTIAL RADIOMETER.[1]

By W. H. DINES.

[Reprinted from *Science Abstracts*, 1921, 24 : 216.]

The instrument consists essentially of a sensitive differential thermometer formed by two test tubes, each containing a few drops of ether, mounted with their axes in a horizontal line and communicating with each other by a U-tube containing ether to form a pressure gage. A metal shield is placed around each tube, with a horizontal slit to admit radiation. The direction from which radiation is admitted to either tube can be controlled by rotating the appropriate shield about the common axis.

Method of use.—There are two ways of using the instrument. In the direct method radiation from a portion of the sky is allowed to fall on one tube while the other is exposed to a full radiator, a vessel containing water, the temperature of which is altered until a balance is obtained. The equivalent radiative temperature of the sky (i. e., the downward radiation from the atmosphere) is then equal to the temperature of the full radiator. In the indirect method, instead of altering the temperature of the full radiator, the tube exposed to the sky is allowed to receive radiation from a second full radiator, of constant temperature, so placed as to effect a balance. A simple calculation then gives the equivalent radiative temperature of the sky.—*M. A. G.*

SIMPLE MAXIMUM ANEMOMETER.[1]

By P. L MERCANTON.

(Reprinted from *Science Abstracts*, 1921, 24: § 339.)

It is often desirable to have instrumental evidence as to the maximum force attained by the wind during a gale, and for this purpose a simple, inexpensive maximum anemometer would be useful. The principle of the Pitot tube suggests itself. Three forms of the instrument have been designed. The first two necessitate the employment of a Dines vane communicating with a manometer. In the first this consists of a U-tube containing oil. The difference between the static and dynamic pressure of the air displaces the oil in the tube, and the farthest point reached is marked by a glass index acting like that in a minimum thermometer. In the second form a metallic Bourdon-Richard manometer is used, recording by a light pivoted index. The third instrument is cheaper, but less accurate. It consists of a glass reservoir with two tubes leading out of it, one vertically and the other obliquely, and at the top each tube has a shore horizontal extension, in the plane of the two tubes. Tht whole is mounted on a vertical pivot and swings with the wind, so that the horizontal extension from the vertical tube faces the wind. The reservoir contains oil, which also enters the lower part of the oblique tube. During wind the oil is consequently forced up the latter, which has at intervals small pockets. These retain small drops of oil when the main body recedes, and the highest pocket so filled marks the approximate height to which the oil ascended, and hence gives an approximate measure of the force attained by the wind. [The diagram illustrating the instrument appears to be printed upside down.]—*M. A. G.*

[1] Jour. Roy. Metl. Soc., London, Oct., 1920, 46:399–405: discussion, 405–406.

[1] *Archives des Sciences*, 2 : 511–513. Nov.–Dec., 1920.

AMERICAN METEOROLOGICAL SOCIETY MEETING IN WASHINGTON, APRIL 20–21, 1921.

The fifth meeting of the American Meteorological Society was held, amid flag-bedecked surroundings, at the central office of the Weather Bureau on the evening of the 20th and morning of the 21st. There were 21 papers on the program, 3 of which were read by title. One of these papers was published in the March REVIEW, one and abstracts of two others are in this REVIEW, and it is expected that the others will appear in full or in abstract in early numbers of the REVIEW.

Various phases of areological work, particularly (1) making of wind-aloft observations, with free balloons, with kites, and clouds; (2) studying the data; and (3) distributing current aerological information and forecasts for aviators by radio. Some aspects agricultural meteorology, mathematics in meteorology, new instruments, and measurements of sky brightness were presented. Those present were particularly fortunate in hearing Dr. John Paraskévopoulos, of Athens, Greece, tell about the meteorological service in Greece. He was spending two months at the central office studying methods and equipment of the Weather Bureau.

A more complete account of the meeting will found in the May or June, 1921, Bulletin of the American Meteorological Society.—*C. F. B.*

THE ARTIFICIAL CONTROL OF WEATHER.

By Sir NAPIER SHAW.

[Abstract reprinted from the *Meterological Magazine*, April, 1921, pp. 60–63; with excerpts inserted from *Aeronautics*, Apr. 7 and 14, 1921. Reprinted also in *Aerial Age Weekly*, May 9, 1921, pp. 203–205.]

On March 9th Sir Napier Shaw delivered a lecture on the artificial control of weather before the Cambridge University Aeronautical Society. A résumé of the lecture is given below.

"The control of weather has been a subject of vivid interest from the dawn of history down to the present day. It is woven into the fabric of every form of civilization. The claims of the rain-maker are in some cases modern; but they are not exclusively modern, and are not to be regarded as one of the many signs of the progress of physical science in civilized nations. * * * Quite deep down in human nature is apparently the feeling that if man can not himself control the weather, at least he knows who or what can; and he can bring influence to bear upon the spirits of the air that will guide the control in the manner desired." Few subjects of speculation are more inter-

esting than the system of control indicated by Greek mythology. Even in the eighteenth century, when as a result of the discovery of the laws of planetary motion the conception of "laws which never shall be broken" was growing on all sides, "the weather was regarded as still at the immediate pleasure of the Almighty Law-giver in Whom had become gathered all the several powers of the Greek immortals." The transition from the mythological position to the theistic position was very gradual, and is perhaps not complete in parts of Europe even to-day.

"In the course of my experience at the Meteorological Office I have had to be responsible for considered opinions on many offers of controlling the weather in some form or other. This was specially the case during the war." Many astonishing suggestions have been made from time to time, but the objects of all of them, good or bad, are curiously limited. "I have never seen any suggestions for beginning where nature begins and turning winter into spring or summer for a particular district by warming the open air or the open sea, or for drying the roads by operating on the humidity of the open air. The objects to which the operations are proposed to be directed are such as the avoidance of hail by the dissipation of thunder clouds. This appeals particularly to the regions which surround the Alps. The production of rain in regions where rain is specially wanted for the maintenance of crops is another object, and, thirdly, the dissipation of fog, and this last has now become transcendently important in flying. The methods proposed are either mechanical or electrical."

The production of noise has always been regarded as influential in controlling the weather, possibly on account of the constant association of rain with the noise of thunder. When firearms were invented their use replaced the ringing of church-bells formerly in vogue among the peasants. The belief in the efficacy of firearms expresses itself periodically in European vine-growing districts. "It was epidemic in a very severe form at the end of last century because somebody had devised a new gun or mortar; pointed upwards it discharged a vortex ring of smoke which could be seen to reach the clouds." The mortars were increased in size until they were 40 feet high, and much money was spent, but the result was indecisive, persons in more northerly latitudes thinking the influence disproved, and those in more southerly ones thinking it proved.

Subsequent French proposals for setting up *paragrêles* "in the form of tall structures carrying metallic points for the discharge of electricity to neutralize the electricity of the thunderclouds" were interrupted by the war.

A variation of the gunfire method is the use of a violent detonation such as is produced by dynamite explosions, heavy gunfire, and so on. "It draws its support largely from the fact that many battles have ended in, or been followed by, downpours of rain. Historically, battles are summer phenomena, and doubtless many summer days of less momentous importance have closed with downpours of rain. * * * There is no ground *a priori* for supposing that concussion would have any effect at all upon the condensation of vapor and clouds And in any attempt to prove the influence by rainfall which occurred subsequently to the explosions we have no means of comparing actuality with what would have happened if the explosion had not occurred. * * * The effect of extensive gunfire may be regarded either as physical, arising from the detonations, or chemical. * * * The direct effect of the detonation is probably nothing at all, and the chemical effect inconsiderable compared with the daily combustion of fuel in the Manchester district."

Mr. Cole, a Canadian airman, suggests rain production by means of liquid air sprayed from an aeroplane. While a certain amount of condensation is thus assured there is a risk that the rain might evaporate before reaching the ground. "A millimeter of rain means 4 tons to the acre, or 2,500 tons to the square mile. To water a countryside would need a good deal of liquid air."

Other rain-making suggestions are even less attractive. The method of throwing dust from an aeroplane on to clouds 5,000 feet high, tried at Pretoria, was unsuccessful, as might be expected, since if cloud is already present dust is superfluous. A similar proposal, using a balloon, was made some years before the war for the dissipation of London fog.

"An electrical installation in Australia for discharging electricity from kites was said to have produced enough rain to fill a large tank in a region that was suffering from lack of rain; but the observations of the time showed that the whole country for hundreds of miles around was uniformly fortunate."

"In the present generation not only are the laws of motion of the heavenly bodies regarded as never to be broken, in spite of the fact that Einstein and others may alter the form; but there are many new laws of physics and chemistry which have an equal claim to be regarded as inexorable in the study of weather; and, moreover, the powers of the laboratory and the workshop have become so much enlarged that the new spirit of humanity is not disposed to take the vagaries of the spirits of the air lying down. If we really understand them we ought to be able to direct the operation of the forces of nature; and we find a disposition to ask whether we can not ourselves take over the forces of the air, and if not, why not?" Many opinions of the futility of human effort have been proved to be wrong; all awkward corners may be turned by new inventions. These matters are largely questions of scale; for practical purposes impossibility is reached when the money and material required exceed the limit of what is available. "We can do anything with a quantity of air in a small inclosure in a laboratory. We can, certainly, by artificial means, make cloud or rain in the inclosure and disperse it or evaporate it at will after it has been formed. We could easily find out whether the detonation of a pistol or a small charge of dynamite at a suitable distance would produce any effect upon an artificial cloud, though I have never heard of the experiment being tried. The important question is whether we can extend such operations from the laboratory to the open air. We are here up against the important consideration that a cube of air 10 meters each way weighs more than a ton. If it is foggy it may contain 5 kilograms of water drops, and a millimeter of rain over the same area weighs 100 kilograms. The amount of heat released by the condensation of a kilogram of water is about 600 kilogram-centigrade units, which are equivalent to 2.5×10^{13} ergs, or approximately one horsepower-hour (2.7×10^{13} ergs). Hence evaporating a 10-meter cube of air containing fog is equivalent to 5 horsepower-hours, and a millimeter of rain over the 10-meter square, 100 horsepower-hours; over a square kilometer, a million horsepower-hours.

"I have another proposal of a different character: This time to arrest and prevent the development of fog at sea by pouring oil on to the water and so stop evaporation in the environment of the ship. In this case, it is not merely the scale; the basic theory is probably at

fault. The water of an Atlantic fog does not, as a rule, come from the surface on which the fog lies, but from far to the south. It is the cold surface which causes the fog; the temperature of the surface is below the dew-point of the air above it, and dew would therefore be formed on the oil. Even if the theory were correct and we obtained a patch of oil, a clear space, and a ship, we should still have to consider what would be their relative positions at the end of an hour or twelve hours, in view of their relative drifts. An identical method was suggested some years ago for application to the river Rhone, at its junction with the Saone, where warm and cold water join. No news has arrived as to the success of the proposal."

The modern problem of clearing fog from aerodromes has been the subject of several suggestions. The chief of these are local heating by means of coal fires, mechanical driving away of foggy air by propellers capable of giving a speed of 100 kilometers per hour to the propelled stream, and electrical methods. Again it is a question of scale. Both within a laboratory and on the larger scale of furnace flues a brush discharge of electricity will clear away dust, smoke and cloud like magic. Sir Oliver Lodge's experiments in clearing Liverpool from fog were not decisive, and in any case it is not very desirable to have an installation for brush discharge, which comes very near to sparking, in the neighborhood of an aerodrome.

"The most telling example of malevolence of the weather toward the allied forces that I can recall in the course of the war is the development of a rainy cyclonic depression over the western front and southern part of the North Sea during the end of July and the beginning of August, 1917. It began to form on July 28, and reached its climax on August 3, when a well-marked depression, 11 millimeters deep, was exhibited on the map, extending over a nearly circular area, 1,400 kilometers in diameter, and had filled up on August 6. It apparently originated and filled up again in the locality. I reckon that the creation of the depression, which was a very small affair, and on the map looked like gerrymandering, is equivalent to the removal from within the cylinder of 1,400 kilometers diameter of seventy thousand million tons of air. It took six days to accomplish this deportation, and three days to fill the space up again. If the enemy accomplished this feat by artificial means, they must have used some other process than firing shells vertically upward: the question gives me the same sort of tired feeling as the 200-mile jetty, with some other sensations added.

"The most direct means of accomplishing such a deportation of air would be by an underground channel to carry the air from the central region to beyond the boundary of the depression. Let us suppose a channel, 12 feet in diameter, leading from Ostend to Berlin and operated there by a 16-foot propeller giving a full bore stream of 100 kilometers an hour (friction being neglected). The deportation would go on at the rate of 1,200 tons per hour, or 28,800 tons per day. Working without intermission, it would take 7,000 years for the propeller to complete the deportation; and as it had to be done in six days, 400,000 such channels would have to be operated concurrently to get the work done in time.

"What it comes to, then, is that all the suggestions for the human control of weather oppress one, not by any mistaken conception of physical processes, but by the 'scale and effect.' Within our knowledge we are lords of every single specimen of the atmosphere which we can bottle up and imprison in our laboratories, our furnace flues and our greenhouses; but in the open air the ordinary inexorable laws which control the behavior of the atmosphere when we are awake and when we are asleep, have such enormous masses of energy in the form of warmth and water vapor in reserve that our own little reserves are not equal to making any serious impression on the course of nature." The course of the weather may, however, be affected by the explosion of a great volcano, and it would be interesting to consider "how far our reserves of available energy compare with the destruction of Pompeii, the disappearance of the island of Krakatoa, or the eruptions of Mont Pelée and La Souffrière."

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SOLAR OBSERVATIONS.

SOLAR AND SKY RADIATION MEASUREMENTS DURING APRIL, 1921.

By HERBERT H. KIMBALL, Meteorologist.

[Solar Radiation Investigations Section, Washington, May 28, 1921.]

For a description of instruments and exposures, and an account of the methods of obtaining and reducing the measurements, the reader is referred to this REVIEW for April, 1920, 48:225.

From Table 1 it is seen that the solar radiation intensities measured very close to normal for April at all stations except Washington, where they were slightly below normal. At Santa Fe, maximum noon intensities of 1.63 cal. on April 8 and 29 are close to the maximum noon reading previously obtained at Santa Fe in April.

Table 2 shows an excess in the radiation received from the sun and sky at Lincoln, a decided deficiency at Madison, and a slight deficiency at Washington during the latter part of the month.

Skylight polarization measurements obtained on three days at Madison when the ground was free from snow give a mean of 60 per cent and a maximum of 67 per cent on the 28th. At Washington, skylight polarization measurements obtained on seven days give a mean of 56 per cent and a maximum of 63 per cent on the 11th. The Washington values are close to average values for April; those for Madison are slightly below the average.

TABLE 1.—*Solar radiation intensities during April, 1921.*

[Gram-calories per minute per square centimeter of normal surface.]

Washington, D. C.

Date.	Sun's zenith distance: 8 a.m. / 75th meridian time. / e.	78.7° / Air mass A. M. 5.0	75.7° / 4.0	70.7° / 3.0	60.0° / 2.0	0.0° / *1.0	60.0° / Air mass P. M. 2.0	70.7° / 3.0	75.7° / 4.0	78.7° / 5.0	Noon. / Local mean solar time. / e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Apr. 1	4.57						1.22	1.04	0.87		3.81
2	4.37		0.73	0.87	1.04	1.33	1.06	0.8	0.79		4.37
4	7.57		0.64	0.82	1.05	1.34	0.96	0.74	0.58	0.48	4.17
5	9.14		0.64	0.77	0.95	1.27	1.04	0.8	0.71	0.58	9.47
6	10.21					1.29					10.21
11	1.96					1.41					2.49
12	3.15		0.77	0.93	1.12	1.42					3.15
19	4.37				1.15	1.34					3.63
20	4.95	0.56	0.71	0.87	1.07	1.2	0.94	0.74	0.57	0.51	4.37
25	10.59	0.62	0.73	0.87	1.08						8.48
Means		(0.59)	0.70	0.85	1.07	1.32	1.04	0.85	0.69	0.52	
Departures		−0.08	−0.04	−0.02	−0.01	−0.05	−0.04	−0.05	−0.06	−0.06	

Madison, Wis.

Date.	8 a.m. e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon e.
Apr. 10	2.49				1.34						2.49
11	3.15				1.33						4.37
18	3.99					1.43	1.10	0.93	0.76	0.66	4.75
19	4.95				1.10	1.29					6.27
23	5.79					1.45					6.27
28	4.17					1.54					5.56
29	4.57					1.44					5.16
Means					1.26	1.43	(1.10)	(0.93)	(0.76)	(0.66)	
Departures					+0.02	+0.02	−0.14	−0.14	−0.11	−0.02	

Lincoln, Nebr.

Date.	8 a.m. e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon e.
Apr. 7	3.63			1.14	1.29	1.44					3.81
11	4.17			1.06							4.75
18	3.81					1.40	1.11	0.88	0.70	0.56	4.95
19	5.79			0.95	1.19	1.31					16.20
21	6.76				1.19						7.29
22	5.7	0.94	1.05	1.11	1.32	1.48	1.23	1.07	0.93	0.81	4.17
23	5.79							0.93	0.79	0.66	7.04
29	5.36			0.80	1.22						6.04
Means		(0.94)	(1.05)	1.01	1.24	1.41	(1.17)	0.96	0.81	0.68	
Departures		+0.16	+0.20	±0.00	+0.01	−0.06	+0.01	−0.02	−0.01	−0.02	

Santa Fe, N. Mex.

Date.	8 a.m. e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon e.
Apr. 8	2.16		1.28	1.37	1.49	1.63		1.27	1.08		1.24
9	1.60					1.58	1.33	1.17	1.03	0.94	1.96
11	3.3	0.74	0.86	0.98	1.19	1.51		1.04			3.45
13	3.45		1.02	1.16							3.45
16	2.26		0.95	1.04	1.16	1.56	1.34				1.88
17	2.74					1.57					2.62
18	2.87						1.32	1.12	0.95	0.80	2.62
20	2.26	0.75	0.85	1.05	1.29						2.26
21	3.3					1.55					3.00
22	2.87		1.11	1.26	1.37	1.60					2.87
23	3.45	0.93	1.04	1.16	1.33						3.15
27	1.88		0.89		1.27	1.54					1.60
28	2.2			1.24	1.3						2.36
29	2.87		1.14	1.27	1.40	1.65	1.39				2.74
Monthly means		0.81	1.01	1.17	1.32	1.58	1.34	1.15	1.02	(0.87)	
Departures		−0.10	−0.06	±0.09	−0.02	+0.04	+0.11	+0.07	±0.00	−0.01	

* Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface.*

Week beginning—	Average daily radiation. Washington.	Madison.	Lincoln.	Average daily departure for the week. Washington.	Madison.	Lincoln.	Excess or deficiency since first of year. Washington.	Madison.	Lincoln.
	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Apr. 2	444	403	434	+51	+18	+ 12	+ 983	−4195	−1164
9	433	311	325	+27	−85	− 50	+1173	−4787	−1514
16	410	468	624	−14	−45	+234	+1072	−5102	− 85
23	382	428	556	−63	− 5	+114	+ 634	−5138	+ 712

MEASUREMENTS OF THE SOLAR CONSTANT OF RADIATION AT CALAMA, CHILE, MARCH, 1921.

By C. G. ABBOT, Assistant Secretary.

[Smithsonian Institution, Washington, May 24, 1921.]

In continuation of preceding publications, I give in the following table the results obtained at Montezuma, near Calama, Chile, in March, 1921, for the solar constant of radiation. The reader is referred to this REVIEW for February, August, and September, 1919, for statements of the arrangement and meaning of the table.

Date.	Solar constant.	Method.	Grade.	Transmission coefficient at 0.5 microns.	Humidity. ρ/ρ s. c.	V. P.	Rel. hum.	Remarks.
1921.								
A. M.	cal.					cm.	Per cent.	
Mar. 1	1.957	$M_{1.27}$	S−	0.867	0.643	0.47	29	Some cloud in east in early morning, later cloudless.
	1.966	$M_{1.20}$						
	1.963	W.M.						
2	1.954	$M_{1.04}$	S−	.864	.670	.59	32	Small patches of cloud scattered about sky.
3	1.968	$M_{1.10}$	S−	.868	.638	.53	30	Cirri in east prevented earlier observations.
	1.951	$M_{1.07}$						
	1.959	W.M.						
4	1.932	M_3	S−	.867	.472	.52	52	Cirri low over high peaks.
	1.945	M_2						
	1.956	W.M.						
P. M.								
5	1.943	$M_{2.17}$	S−	.862	.487	.52	25	Clouds over high peaks.
	1.910	$M_{2.55}$						
	1.943	W.M.						
A. M.								
6	1.942	$M_{1.23}$	S−	.858	.570	.55	33	Small cumuli disappearing in east.
	1.957	$M_{1.18}$						
	1.946	W.M.						
7	1.955	$M_{1.19}$	S−	.859	.563	.58	32	Cumuli over high peaks, also in west.
	1.947	$M_{1.14}$						
	1.952	W.M.						
10	1.957	$M_{1.03}$	S−	.864	.648	.38	17	Clouds scattered about sky.
13	1.949	$M_{1.31}$	S−	.858	.545	.58	40	Cirri in various parts of sky.
P. M.								
14	1.868	$M_{1.91}$	U	.863	.498	.48	21	Cirri scattered about sky.
A. M.								
17	1.955	$M_{1.11}$	S−	.867	.672	.39	15	Clouds over high peaks.
	1.943	$M_{1.07}$						
	1.950	W.M.						
18	1.913	M_2	S	.858	.483	.33	24	Do.
	1.916	$M_{1.76}$						
	1.915	W.M.						
P. M.								
19	1.946	$M_{1.25}$	S−	.861	.594	.47	22	Few clouds over high peaks.
	1.952	$M_{1.30}$						
	1.948	W.M.						

WEATHER OF NORTH AMERICA AND ADJACENT OCEANS.

NORTH ATLANTIC OCEAN.

By F. A. YOUNG.

The average pressure for the month was very much above the normal at land stations on the coasts of Newfoundland, Canada, the British Isles, and in the Bermudas; it was slightly above on the Atlantic and Gulf coasts of the United States, as well as at Turks Island and San Juan, Porto Rico, while there was a small negative departure at Horta, Azores, and Swan Island.

The number of days with winds of gale force was apparantly somewhat below the normal over the northern steamer lanes, and above over the region between 35th and 45th parallels and the 25th and 40th meridians.

Fog was prevalent over the Grand Banks, in the vicinity of the British Isles and off the American coast, north of Hatteras, while few reports were received from vessels in mid-ocean.

On April 1 and 2 there was a slight disturbance of limited extent central a short distance south of Halifax, N. S., while over the remainder of the ocean high pressure and light to moderate winds prevailed. The storm log from the American S. S. *Henry Steers* follows:

Gale began on the 1st, wind SW. Lowest barometer 29.68 inches at 5 a. m. on the 2d, wind SSW., 8; position, latitude 40° 07′ N., longitude 63° W. End of gale on the 2d, wind NW., 9. Highest force of wind 9, SW.; shifts near time of lowest barometer SSW.-SW.-WNW.

From the 3d to the 6th conditions were comparatively featureless, as only one vessel reported heavy weather during that period. Storm log follows:

American S. S. *Editor:*

Gale began on the 4th, wind SW. Lowest barometer 29.72 inches at 4 p. m. on the 6th, wind WNW., 10; position, latitude 44° 55′ N., longitude 36° 56′ W. End of gale on the 7th, wind WNW. Highest force of wind 10, WNW.; shifts SW.-S.-W.-NW.

Charts IX and X show the conditions on April 8 and 9, respectively, when the midsection of the steamer lanes was swept by one of the severest storms of the month. Storm logs follow:

American S. S. *Editor:*

Storm began on the 8th, wind N. Lowest barometer 29.76 inches at 9 a. m. on the 8th, wind N., 10; position, latitude 42° 52′ N., longitude 42° 57′ W. End of gale on the 9th, wind N. Highest force of wind 10, N.; steady from N.

Dutch S. S. *Sliedrecht:*

Gale began on the 8th, wind WSW. Lowest barometer 29.80 inches at 8 a. m. on the 8th, wind WNW., 10; position, latitude 35° 12′ N., longitude 37° 05′ W. End of gale on the 9th, wind NNW. Highest force of wind 10, WNW.; shifts WSW.-NNW.

Swedish S. S. *Stockholm:*

Gale began on the 8th, wind NE. Lowest barometer 29.68 inches at 4 p. m. on the 8th, wind NNE.; position, latitude 48° 20′ N., longitude 38° 10′ W. End of gale on the 9th, wind N. Highest force of wind 11; shifts not given.

On the 10th there was a LOW in southern waters, central near latitude 32° N., longitude 42° W.; this moved slowly eastward, and on the 12th and 13th the center was near the Azores. A few vessels encountered moderate to strong gales during this disturbance, and the storm logs follow:

Dutch S. S. *Almelo:*

Gale began on the 9th, wind N. Lowest barometer 29.26 inches at 2 p. m. on the 13th, wind WSW., 3; position, latitude 36° 33′ N., longitude 34° 42′ W. End of gale on the 14th, wind ENE. Highest force of wind 9, NNW.; shifts S.-SE.-E.

Italian S. S. *Georgia:*

Gale began on the 12th, wind NE. Lowest barometer 29.20 inches at 2 p. m. on the 13th, wind ENE., 10; position, latitude 38° 55′ N., longitude 33° W. End of gale on the 13th, wind ENE. Highest force of wind 10, ENE.; shifts ENE.-N.

Chart XI for April 11 shows the unusual condition that existed in the Gulf of Mexico, where strong northerly gales prevailed, accompanied by high barometric readings. A HIGH with a crest of over 30.50 inches was central near Memphis, Tenn., while the center of the LOW as shown on Chart XI is some distance south of Nantucket. Storm logs follow:

American S. S. *Kekoskee:*

Gale began on the 10th, wind N. Lowest barometer 30.30 inches at noon on the 10th, wind N.; position, latitude 21° N., longitude 97° W. End of gale on the 11th, wind N. Highest force of wind 10, N.; wind steady from N.

American S. S. *El Sud:*

Gale began on the 11th, wind NNE. Lowest barometer 30.18 inches at 2 a. m. on the 11th, wind N., 7; position, latitude 26° N., longitude 88° 17′ W. End of gale on the 11th, wind N., 7. Highest force of wind 7, N.; steady from N.

American S. S. *Heredia:*

April 11th, 5 a. m.; position, latitude 20° 41′ N., longitude 86° 30′ W. Strong wind sets in from N. with heavy rain squalls and heavy seas; sky overcast. Shipping water forward from 8 a. m. on the 11th to 4 a. m. on the 12th, when wind and sea moderated.

The LOW shown on Chart XI drifted slowly eastward, and on the 12th the center was near latitude 40° N., longitude 60° W.; the storm area was of limited extent, and the depression gradually filling in, practically disappeared by the 13th.

Storm log follows:

British S. S. *Kabinga:*

Gale began on the 11th, wind S. Lowest barometer 29.80 inches on the 11th, wind S., 12; position, latitude 39° 27′ N., longitude 63° 56′ W. End of gale on the 13th, wind N. Highest force of wind 12, S.; shifts S.-SSW.-NW.-N.

On the 12th the American S. S. *Steelmaker* experienced heavy weather in the vicinity of Porto Rico, as shown by the following extract from the daily journal:

On April 12, Greenwich mean noon position, latitude 19° 45′ N., longitude 74° 12′ W. Weather overcast, fresh breeze to moderate gale, heavy sea, vessel laboring and shipping water fore and aft.

From the 14th to the 17th, inclusive, there was a disturbance over northern Europe, and land stations in the British Isles, as well as vessels off the coast, reported moderate to strong northerly gales.

Storm logs follow:

American S. S. *Tekoa:*

Gale began on the 14th, wind W., 6. Lowest barometer 29.25 inches at 10 a. m. on the 14th, wind WNW., 8; position, latitude 55° 40′ N., longitude 5° 45′ E. End of gale on the 15th, wind NW., 6. Highest force of wind 10, WNW.; steady from WNW.

British S. S. *Vasari:*

Gale began on the 15th, wind NW. Lowest barometer 29.64 inches at 6 a. m. on the 17th, wind NW., vessel at Liverpool. End of gale on the 17th, wind N. Highest force of wind 9, NW.; shifts NW.-SW.-WNW.-NW.

Norwegian S. S. *George Washington:*

Gale began on the 15th, wind NW. Lowest barometer 29.50 inches at 6 a. m. on the 16th; wind NW., 8; position, latitude 56° 50′ N., longitude 20′ W. End of gale on the 17th, wind NNE. Highest force of wind 8, shifts NNW.-N.-NNE.

During the period from the 14th to the 17th, moderate weather was the rule over the steamer lanes with fog

over the Grand Banks. On the 16th winds of gale force were reported off the coast of Mexico as shown by the following storm log:

American S. S. *Saramacca:*

Gale began on the 15th, wind ESE.; lowest barometer 29.76 inches at 4 a. m. on the 16th, wind E., 7; position, latitude 17° 18′ N., longitude 86° 47′ W. End of gale on the 16th, wind E., 6. Highest force of wind 8, E.; shifts not given.

From the 18th to the 26th there were no well-defined disturbances of any marked intensity, although during this period some vessels in widely scattered sections of the ocean experienced moderate gales, as shown by the following storm logs:

British S. S. *Cornishman:*

Gale began on the 19th, wind SSW. Lowest barometer 29.76 inches at midnight, 19th, wind WSW., 7; position, latitude 50° 39′ N., longitude 24° 1′ W. End of gale on the 20th, wind NNW. Highest force of wind 8; shifts SSW.-NW.

American S. S. *West Mahomet:*

Gale began on the 20th, wind SSW. Lowest barometer 29.80 inches at 3 p. m. on the 20th, wind SW., 7; position, latitude 41° 08′ N., longitude 56° 15′ W. End of gale on the 20th, wind W. Highest force of wind 9, SW.; shifts SSW.-SW.-W.

British S. S. *Missouri:*

Gale began on the 24th, wind ESE. Lowest barometer 29.89 inches at 11 p. m. on the 24th, wind WSW., 3; position, latitude 40° 38′ N., longitude 64° 03′ W. End of gale on the 25th, wind W. Highest force of wind, 9; shifts SSE.-SW.-WSW.

British S. S. *Collingsworth:*

Gale began on the 25th, wind NW. Lowest barometer 29.42 inches at 3:45 a. m. on the 28th, wind NNW., 7; position, latitude 42° 31′ N., longitude 40° 39′ W. End of gale on the 29th, wind N. Highest force of wind, 10, NNW.; shifts not given.

Between dates recorded on gale report force of wind continually varied dropping to force 6 several times for short periods; held to northwesterly points, except it was W. by S. for about eight hours on the 27th. Frequent rain and hail squalls.

The British S. S. *Cretic* encountered an unusually strong current as shown by the following report:

From noon April 23, position, latitude 40° 56′ N., longitude 40° 38′ W., to noon April 24, position, latitude 41° 31′ N., longitude 48° 55′ W., vessel set west 23 miles by careful calculation. During this period the temperature of the air fell from 67° to 42° F. and that of the water from 64° to 44° F. Wind WNW., 5; NW., 5 to 6; N., 5.

At 7 a. m. on the 27th, while about half way between Progresso and Habana, the American S. S. *Esperanza*, Capt. Avery, was in the vicinity of a water spout, that appeared to be about a mile high, although its base was shrouded in mist and its crest lost in the clouds. It was first observed by George K. Ludwigsen, first officer, who was on watch at the time, and was visible for about two hours. This phenomenon was at one time near the vessel, and the captain tried to break it by blowing the whistle, but this means proving ineffective, the life-line mortar was fired and the spout collapsed.

On the 27th there was a LOW central near latitude 45° N., longitude 35° W. that afterwards developed into an unusually severe disturbance as shown by Charts XII and XIII for April 28 and 29, respectively. It remained nearly stationary until the end of the month, and on the 30th was apparently beginning to fill in, and no winds of gale force were reported on that day.

Storm logs follow:

Dutch S. S. *Kinderdijk:*

Gale began on the 26th, wind WNW., 7. Lowest barometer 29.14 inches at 4 p. m. on the 28th, wind SW. 6; position, latitude 44° 12′ N., longitude 29° 32′ W. End of gale on the 29th, wind SSE., 3. Highest force of wind 10; shifts NW.-SWS-SE.

British S. S. *Verbania:*

Gale began on the 27th, wind SE. Lowest barometer 28.97 inches inches at 8 a. m. on the 28th, wind E., 7; position, latitude 29° 41′ N., longitude 32° 40′ W. End on the 29th, wind N. Highest force of wind 9, NNE.; shifts ESE.-E.-NE.

Danish S. S. *Oscar II:*

Gale began on the 28th, wind ENE. Lowest barometer 28.93 inches at 2 p. m. on the 29th, wind NNW., 10, position, latitude 27° 10′ N., longitude 40° 36′ W. End of gale May 1, wind WNW. Highest force of wind, 11, NNW.; no shifts near time of lowest barometer.

American S. S. *American:*

Gale began on the 28th, wind SE. Lowest barometer 29.45 inches at 6 p. m. on the 28th, wind SE., 7; position, latitude 45° 50′ N., longitude 27° 30′ W. End of gale on the 30th, wind E. Highest force of wind, 8, SE.; shifts NE.-N.-NE.-SE.-E. SE. wind predominated during this gale.

NORTH PACIFIC OCEAN.

By F. G. TINGLEY.

Pressure at the island stations of Dutch Harbor, Midway Island, and Honolulu averaged near the normal for the month and there were no especially marked conditions at any time at these stations. Over the ocean as a whole, however, high pressure predominated. The highest pressure at Dutch Harbor, 30.24 inches, occurred on the 1st and the lowest, 28.98 inches, on the 8th. At Honolulu the highest pressure, 30.20 inches, occurred on the 11th and 12th and the lowest, 29.90 inches, on the 1st. At Midway Island pressure was above normal on eight days in the first decade, two days in the second decade, and five days in the last decade. The highest pressure, 30.30 inches, occurred on the 5th and 6th and the lowest 29.86 inches on the 30th.

At the beginning of the month a belt of high pressure, covering the middle latitudes of the ocean, stretched from the coast of Asia to the coast of North America. There appeared to be two centers within this belt, one over Japan having a central reading of 30.53 inches, another of somewhat lesser magnitude between Dutch Harbor and Honolulu.

On the 1st a depression formed in the vicinity of Taiwan. With the eastward movement of the anticyclone over Japan during the succeeding several days this depression moved to the northward, merging with two others, one of which advanced over China, the other over the Yellow Sea. By the 4th these depressions had united to form a storm which was especially severe over the southern coasts of Japan. Reports indicate that some 30 lives were lost and great property damage occurred. In the harbor of Yokohama the Japanese S. S. *Alabama Maru* and *Atlas Maru* dragged their anchors and went aground, but subsequent reports of their movements indicated that neither sustained material damage. The former vessel had its passengers aboard and was about to sail for Seattle. The American S. S. *Golden State* arrived at Yokohama from Honolulu on the 4th, successfully weathering the gale.

While this storm prevailed on the western side of the Pacific the anticyclonic center which on the 1st lay between Dutch Harbor and Honolulu advanced eastward to the North American coast, increasing in energy, the central readings exceeding 30.50 inches. Its advance was marked by a strong to whole westerly gale off the middle Pacific coast on the 2d, 3d, and 4th.

The American S. S. *Richmond*, Capt. Jos. Fuchs, San Francisco for Honolulu, encountered this gale on leaving

port. Mr. C. D. Johnston, second officer and observer, states that it began on the 2d. The lowest barometer was 30.04 inches at 5 p. m. on that date, after which pressure rose rapidly, reaching 30.40 inches early on the 4th. The highest force of the wind was 10, NW., on the 3d.

The American S. S. *Admiral Sebree*, Capt. F. Nystrom, Observer C. A. Christiansen, second officer, had this gale on the 3d and 4th while proceeding down the coast from Ocean Falls, B. C., to San Francisco. The highest force of wind was 10, W., on the 4th.

Following the eastward movement of the anticyclone on whose front this gale occurred, low pressure developed in the vicinity of the Aleutians, from which a short series of depressions resulted. These advanced over the Gulf of Alaska, causing southeasterly gales along the eastern portion of the steamer lanes at intervals until about the 12th.

The American S. S. *Northwestern*, Capt. Wm. Jensen, returning to Seattle from Alaskan ports had an unusual experience in connection with one of these depressions. Observer P. Christiansen makes the following note:

We left Cordova southbound at 2:15 p. m. April 10, barometer 29.56, strong easterly wind and rain; anchored off Johnstone Point at 6:40 p. m., barometer 29.47, strong SE. gale, rain. About noon April 11 weather began to moderate but barometer continued to fall slowly and steadily. At 5 p. m. of the 11th left anchorage, barometer 29.25, light NE. wind and rain; 12 midnight, barometer 29.12, light NE. wind and cloudy. At 2 a. m. April 12, barometer began to rise and vessel soon ran into an E. to SE. gale. The barometer continued to rise. It seems that the barometer followed the weather in this case.

The explanation of the experience of the *Northwestern*, as shown by the weather map, is as follows: When leaving Cordova the vessel was on the eastern side of a small depression which was advancing slowly eastward, both traveling at about the same rate. When the *Northwestern* came to anchor off Johnstone Point, the depression overtook the vessel, which for some hours on the 11th was in the relatively calm center, with a low barometer. During the night of the 11th–12th, when the vessel was again proceeding southeastward the center of the depression receded somewhat to the westward and began to fill up. The *Northwestern*, continuing on her course, thus found herself again involved in the gale on the eastern side of the depression, with a rising barometer.

The British S. S. *Empress of Japan*, Capt. W. Dixon, R. D. R. N. R., Yokohama (March 31) for Vancouver, was involved in an earlier depression of this series. Mr. G. Clarke, second officer and observer, has submitted the following storm log:

Gale began on the 7th, wind SSE., lowest barometer 29.64 inches at 4 p. m. of the 7th in latitude 52° N., longitude 158° 30′ W.; gale ended on 8th; highest force of wind 9, SE.; no shifts.

The Japanese S. S. *Fushima Maru*, Capt. Shimiyu, Yokohama (March 25) for Victoria, experienced these gales on the 2d and 5th. On the former date, when in about longitude 166° W., the wind reached force 8, veering from SE. at 7 a. m., through S. at noon and SW. at 3 p. m., to W. at 8 p. m. Lowest barometer 29.43 inches. On the 5th, when in about longitude 144° W., the barometer fell to 29.63 with a strong gale from SE. and S. The *Fushima Maru* had previously experienced a fresh northwesterly gale on March 25, soon after leaving port and a whole gale on the 29th, near longitude 160° E. On the latter occasion the wind veered from SE. at 7 a. m. of the 29th to NW. at 4 p. m. of the 30th.

On April 11 two vessels on the southern route near the 160th meridian, east longitude, experienced heavy weather. One of these vessels was the American S. S. *Westmoreland*, Capt. Clifford J. Stewart, Honolulu (April 2) for Shanghai. Mr. F. F. Nann, second officer and observer, has submitted the following account of conditions on that date:

Monday, April 11, position 26° 30′ N., 160° 13′ E., weather fine and clear, sea smooth, wind SW., 4. At 2:15 p. m., same day, wind shifted to westward and a black cloud bank appeared in the northwest. By 2:30 p. m. there was a strong NW. wind and driving rain, wind shifting at once to N. By 4 p. m. the wind was NE., force 7, and a high sea was breaking over vessel. At 4:30 p. m. changed course from 279° true to 250°, changing back at 7 p. m. At 5 a. m. of the 12th the wind was easterly, force 5; near noon the sea moderated and sky cleared. The barometer did not change more than 0.05 inch throughout the gale.

The gale described by Mr. Nann was probably due to an ill-defined depression formed on the front of an anticyclone which, following the depression of the 3d–4th at the south of Japan, appeared to have its center somewhat to the east of Japan on the 11th.

The American S. S. *West Henshaw*, Capt. O. B. McMullen, Cadiz (P. I.) for San Francisco, had an experience very similar to that of the *Westmoreland*. Mr. H. F. Foster, the observer, states that at about 3:45 or 4 p. m., of the 11th, when the vessel was near latitude 28° 11′ N., longitude 165° 59′ E., the wind, which during that day had been easterly and light, veered to NW. by W. and increased to a moderate gale. It held between this point and N. until about 2 p. m. of the 12th when it veered to N. by E. and during the following night to NE., when it diminished to a fresh breeze.

It will be noted that the gale lasted some 24 hours longer with the *West Henshaw* than with the *Westmoreland*, the former vessel being eastward, the latter westward bound.

NOTES ON WEATHER IN OTHER PARTS OF THE WORLD.

North Atlantic Ocean.—On April 8 the U. S. Hydrographic Office sent out a notice to mariners urging them to shift the sailing routes 60 miles southward because of the numerous ice fields in the regular steamer lanes.

Central Europe.—According to press advices the great drought which had persisted for six months over Central Europe, particularly in Switzerland, Austria, Hungary, and Rumania, was brought to an end in early April by the advent of heavy snows in the Alps and copious rains in the lowlands. Prior to this precipitation period, agricultural conditions had reached an acute crisis. In Switzerland and Austria there was little pasture for cattle and hence little butter, milk, or cheese.

British Isles.—There was a very general deficiency in rainfall throughout the British Isles during April. Only restricted areas in England, Wales, and Ireland had as much as 2 inches. The general rainfall, expressed as a percentage of the average, was: England and Wales, 59; Scotland, 61; Ireland, 46; British Isles, 56.

In London (Camden Square) the month was fine and pleasantly mild, but with a cold snap and snow showers between the 15th and 17th. The mean temperature was 49.5° F., or 1.5° F. above the average.[1]

France.—Temperature in France, which had been unusually high, fell rapidly, and on the 15th the rain turned to snow and sleet, which lasted for several days.

Mexico.—A severe eruption of the volcano of Popocatepetl occurred early in April. This is a recrudescence of the activity which began in the spring of 1920, after 200 years of quietude. In the past the dust associated with volcanic eruptions has been responsible for considerable meteorological effects, especially a diminution in the heat and light from the sun, and brilliant sunset coloration, a noteworthy example being Krakatoa in 1883, and it will be interesting to observe if similar effects follow in this case.[1]

[1] *The Meteorological Mag.*, May, 1921, 56: 111-112.

DETAILS OF THE WEATHER OF THE MONTH IN THE UNITED STATES.

CYCLONES AND ANTICYCLONES.

By W. P. DAY, Observer.

Low-pressure areas were numerous, many of which first took form over the southwestern States, grew in intensity over the central valleys but lost energy as they approached the coast or the northern border. Hudson Bay HIGHS were persistent during much of the month and effectively deranged the normal movement of weather.

The table below gives the number of HIGHS and LOWS by types:

Lows.

	Alberta.	North Pacific.	South Pacific.	Northern Rocky Mountain.	Colorado.	Texas.	East Gulf.	South Atlantic.	Central.	Total.
April, 1921	5.0	......	3.0	2.0	2.0	4.0	......	3.0	1.0	20.0
Average number, 1892-1912	3.4	1.6	0.9	0.5	1.3	1.0	0.3	0.6	0.7	10.3

Highs.

	North Pacific.	South Pacific.	Alberta.	Plateau and Rocky Mountain region.	Hudson Bay.	Total.
April, 1921	3.0	....	3.0	1.0	5.0	12.0
Average number, 1892-1912	1.6	1.6	3.1	1.0	0.6	7.9

THE WEATHER ELEMENTS.

By P. C. DAY, Climatologist and Chief of Division.

[Weather Bureau, Washington, June 1, 1921.]

PRESSURE AND WINDS.

During the first half of the month pressure changes continued slight in the main, and the lull in cyclonic and anticyclonic activities that had marked the preceding months of the present year continued, except that unusually high pressure of the Hudson Bay type overspread the Northeastern States and Canadian Maritime Provinces near the middle of the first decade, and pressure was high over the central valleys and southeastern districts during the latter part of the first and the early part of the second decades.

Near the middle of the month, however, the weather became more unsettled, particularly over the Southwest, where on the morning of the 15th pressure was unusually low and stormy conditions existed over practically all districts eastward and northeastward. This storm in its eastward movement brought the heaviest precipitation of the month over most central and eastern districts and was accompanied by heavy, wet snow and high winds over portions of the Great Lakes region, and thence eastward, causing interruptions to wire communications, while to the southward tornadoes, thunderstorms, and high winds caused death or injury to a number of persons, and heavy property losses. This was promptly followed by a high pressure area of considerable magnitude, and during the 17th and 18th unusual cold was experienced in the central valleys and southern districts, particularly in Texas, Oklahoma, Arkansas, and portions of adjoining States.

By the first of the third decade pressure had again become low in the Southwest, and cloudy, rainy conditions soon overspread the central valleys, precipitation becoming general during the following two or three days over all districts from the Mississippi River eastward, the falls in general being the second heaviest of the month in numerous sections. As this storm was passing into the ocean from off the southern New England coast a third storm area of wide extent was developing in the Southwest, attended by unusually low pressure, the barometer at Roswell, N. Mex., on the morning of the 24th reduced to sea level, indicating a value of 29.22 inches, the lowest ever observed at that station.

This storm area moved slowly eastward but without the usual precipitation in advance of the center, due doubtless to the strong southerly winds and rapidly rising temperature along its eastern front. Later on, however, thunderstorm conditions developed in the Mississippi Valley districts, and by the morning of the 27th a storm of considerable intensity was central in the upper Lake region, which gradually moved northerly toward the Hudson Bay district during the following day. Offshoots from this, however, appear to have

developed in the eastern districts, bringing unsettled weather with local showers from the Ohio Valley eastward to the Atlantic coast and northeastward to New England.

The pressure for the month as a whole exhibited the type that prevailed so persistently during the past winter and so far this spring, higher than normal over the southern districts and comparatively low along the northern border. As in preceding months, southerly winds prevailed extensively in all districts from the Great Plains eastward, extending into the far Northern States.

A slight decrease in pressure over the plateau region as compared with the normal, and a corresponding or larger excess over the Pacific Coast States, particularly in the more northern districts and extending into the far western Canadian Provinces, caused a general drift of cool northerly or westerly winds into the districts west of the Rocky Mountains.

In the absence of marked variations in pressure, wind velocities were not usually high over any extensive areas although some severe local storms occurred, notes regarding which follow at the end of this paper.

TEMPERATURE.

The daily variations in temperature during the month were unusually small, and while there were several periods of severe cold for the season, these were mostly the result of several days of falling temperature.

The principal periods of cold were on the 7th and 8th, when the lowest temperatures of the month occurred over the greater part of the Rocky Mountain and plateau regions, extending during the 9th and 10th into the Great Plains, and during the following two days over most of the central valleys and eastern districts. In the far Southwest this period gave temperatures as low as, or lower than, had ever been observed in April. On the 16th and 17th cold weather again overspread the eastern Plains and portions of the Mississippi Valley, the lowest temperatures of the month occurring over the States immediately west of the Mississippi River from Iowa to the Gulf of Mexico. At points in Arkansas and along the Texas coast the temperatures during this period were likewise the lowest ever experienced so late in the month. The last decade was mostly free from temperatures unusual to the season, although about the 24th and 25th the coldest weather of the month was reported from small areas in the middle Rocky Mountain and Plateau districts.

Temperatures below zero were reported from several western mountain States and from exposed points in northern Maine, and freezing temperatures occurred in all parts of the country at some time during the month, save in portions of Florida and along the immediate south Atlantic, Gulf, and Pacific coasts, and at the lower elevations of California and southern Arizona.

The periods of greatest heat were widely scattered throughout the month, the most extensive being on the 3d and 4th, in the Rocky Mountain and adjacent regions, and about the 25th and 26th over most districts from the Great Plains eastward to the Atlantic. The last few days were the warmest of the month in the far Southwestern States when temperatures passed above 100° F. at points in Arizona and southern California.

The mean temperature of the month continued above the normal, as has been the case for a number of months over all northern and central districts from the Great Plains eastward, the month being particularly warm in the Great Lakes, Ohio Valley, and Atlantic Coast States, where locally it was the warmest April of record.

In sharp contrast with the persistent warmth of the eastern districts of the United States, the temperatures to the southeastward appear to have been unusually low. At San Juan, P. R., the month was cold throughout, in fact no day had temperature above the normal and the average for the month was the lowest of record for April.

From the middle Gulf States westward to the Pacific coast, and generally in the Rocky Mountain and plateau regions, the month was cooler than the average, and decidedly so in Idaho and portions of adjoining States.

PRECIPITATION.

Principal periods of precipitation during the month were on the 1st over the eastern quarter of the country, where the falls were general and locally heavy; from the 6th to 9th when rainy conditions moved slowly from the Rocky Mountain region to the Atlantic coast, during which time the heaviest rainfall of the month occurred at points in Texas and over considerable areas in the Ohio and Mississippi Valleys; from the 13th to 17th, when precipitation was general, and frequently copious, from the southern Plains eastward and northeastward to the Atlantic coast, some unusually heavy snows occurring in northern Illinois, southern Wisconsin, and portions of adjoining States; about the 21st to 24th from the eastern Plains to the Atlantic coast precipitation was general and locally heavy in portions of the Mississippi Valley and Gulf States. This was almost immediately followed by a stormy period, which prevailed during the latter part of the month from the Rocky Mountains eastward, attended by local showers and occasionally heavy rains.

For the month as a whole precipitation was generous and above normal from central Texas and the middle Gulf States northeastward to the Great Lakes and New England, and it was usually sufficient for present needs over most other districts from the Great Plains eastward, and generally over the central and northern Rocky Mountain districts, and in the far Northwest.

In portions of the Southwest, the month was entirely without precipitation, and the drought was becoming severe particularly in western Texas, southern New Mexico, and portions of Nevada.

SNOWFALL.

Heavy falls of snow in the central Rocky Mountains during April added materially to the depths previously accumulated, and there were considerable additions to the snow cover in the high mountains of Utah and northern Nevada. But little snow seems to have fallen in the mountains of California and thence northward, except locally in Washington.

Heavy snow for the season of the year occurred on the 16th and 17th, from the Great Plains eastward to the Lake region, the falls in Iowa, northern Illinois, and southern Wisconsin, ranging frequently up to as much as 12 inches, the heaviest ever recorded in April. The general distribution of snowfall over the country is indicated on Chart VIII of this REVIEW.

RELATIVE HUMIDITY.

There was much diversity in the moisture distribution, which appeared to show little relation to the rainfall conditions. In general, relative humidity was above

normal in the Middle and North Atlantic States, over the Great Lakes, and portions of the Ohio and Mississippi Valleys and in the central Rocky Mountain and Plateau regions. It was usually less than normal in the Appalachian Mountains, the East Gulf and South Atlantic States, and from Texas westward to the Pacific.

LOCAL STORMS.

April 5.—Early in the morning a severe storm swept over Wharton, Wharton County, Tex., injuring two people and causing about $40,000 property loss.

Also, during the night a tornado caused about $250,000 property damage at Clarendon, Donley County, Tex. No loss of life.

April 6.—A small tornado occurred near Beyersville, Williamson County, Tex., about 8 a. m. The storm

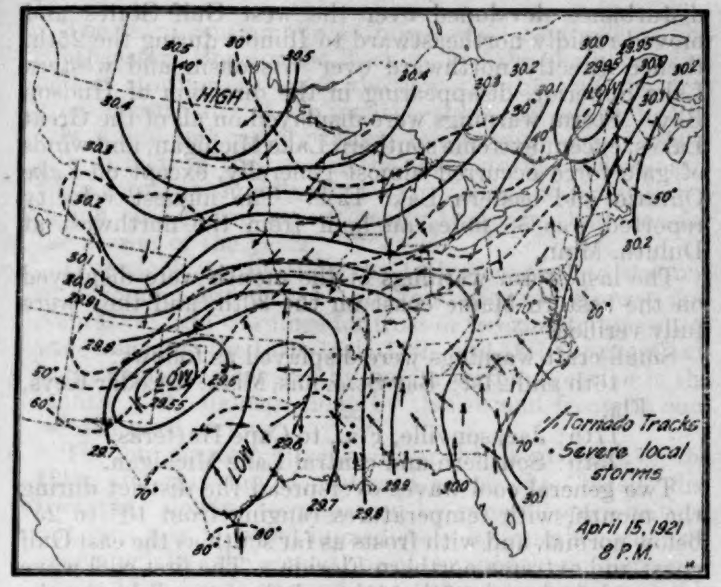


Fig. 1.

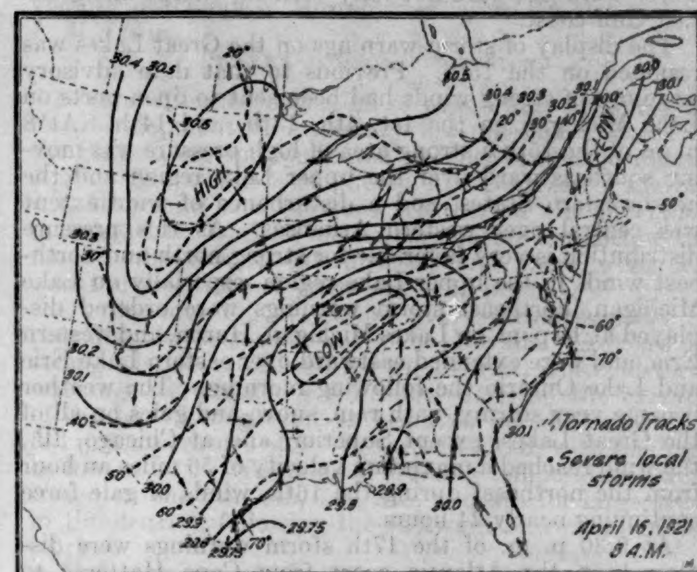


Fig. 2.

covered a distance of about 20 miles from near Elgin in the extreme northwestern part of Bastrop County to near Thorndale in the extreme southwestern part of Milam County. Width of storm averaged from 80 to 100 feet. No loss of life, due partly to sparsely settled conditions. Property loss about $20,000. About fifteen houses destroyed.

April 13.—A tornado struck the town of Melissa in northern Texas at 2:45 p. m. The storm covered a wide area and swept as far south as Jacksonville, Tex. Eight persons were killed, and more than fifty injured. Practically every building in the business section of Melissa and many dwellings were demolished.

April 15.—A series of four tornadoes occurred in northern Texas and western Arkansas. The principal storm was first observed in northern Texas, but no great damage occurred until it had crossed the State boundary into Arkansas. The others were less destructive and were all confined to the latter State. (See fig. 1.) Full details covering these storms appear in another portion of this REVIEW.

April 15–16.—A severe gale and blizzard moved from Colorado to the upper Lake region. From six to sixteen inches of snow fell and much damage resulted from the wind and heavy snow. (See weather maps, figs. 1 and 2.)

April 15–16.—Severe local storms traversed portions of seven counties in Mississippi, causing the loss of two lives, injury to about 25 persons, and considerable property damage. Full details of this storm are published in another portion of this REVIEW.

April 16.—Four tornadoes occurred in the early morning in Tennessee (see fig. 2), resulting in 2 people killed, and about 30 injured, and property loss of about $100,000. Details are published on pages 198–199, above.

A severe storm during the morning at Birmingham, Ala., injured a number of persons and caused property loss estimated at $100,000 to $200,000. At other points in Alabama storms of tornadic character, together with severe local thunderstorms and heavy rains, caused the death of more than a dozen persons, injury to more than 50, and damage estimated at more than $1,000,000. Full details of these storms are published on pages 197–198.

April 16–17.—Severe storm with heavy wet snow at Port Huron, Mich., caused much damage to overhead wire systems.

April 19.—A heavy wind storm occurred in the vicinity of Otto, Santa Fe County, N. Mex., during the afternoon, causing considerable property loss.

April 22.—A storm having some features of a tornado occurred near Thomasville, Ga., during the afternoon. Path about 4 miles long and 20 yards wide. No lives lost and property damage about $1,000.

April 23.—A small tornado visited portions of Polk County, Fla., about 50 miles east of Tampa, during the early morning and destroyed a number of houses and caused property loss of about $20,000. No one killed but several injured.

April 25.—A few persons were injured and considerable property damage occurred in several central and midwestern counties of Wisconsin during a severe wind storm.

Muscatine, Iowa, was visited about noon by a severe wind storm. Several buildings were unroofed or blown down. Also, during the afternoon in the vicinity of Dubuque, Iowa, a severe storm caused considerable property loss.

Central Illinois was likewise visited by a severe wind and rain storm during the night of the 25th that destroyed some property.

April 26.—Small tornadoes were reported at Carlisle and Gould, Ark., on the morning of the 26th. Estimated property damage $20,000, No loss of life.

A tornado swept over Braxton, about 25 miles south of Jackson, Miss., about 3 p. m. of the 26th. Hardly a building was left standing in the town. Fifteen persons were reported killed, 23 injured, and $100,000 property loss.

A hail and wind storm visited Teague, Tex., during the night of the 26th and destroyed some property.

April 29.—Severe wind and dust storm in Sheridan, Wyo., caused much damage to wires and light structures.

STORMS AND WARNINGS—WEATHER AND CROPS.

STORMS AND WEATHER WARNINGS.

WASHINGTON FORECAST DISTRICT.

During the first two weeks of the month there were no storm warnings issued, except for the Maine coast on the 11th, for the east Gulf coast from Bay St. Louis, Miss., to Cedar Keys, Fla., on the 13th and for the Atlantic coast from Norfolk, Va., to Boston, Mass., on the 14th. These warnings were not fully verified, except along the east Gulf coast.

The display of storm warnings on the Great Lakes was resumed on the 15th. Previous to that date advisory warnings of strong winds had been sent to open ports on Lake Michigan on the 1st, 4th, 13th, and 14th. At 8 p. m. of the 15th a strong area of high pressure was moving southeastward over the upper Lake region and the northwestern States, and a disturbance of wide extent was central over western Arkansas. As this pressure distribution is very favorable for strong north and northeast winds in the upper Lake region, especially on Lake Michigan, northeast storm warnings were ordered displayed at 10 p. m. on Lakes Michigan, Huron, and western Erie, and were extended eastward over eastern Lake Erie and Lake Ontario the following morning. The weather became very stormy, with rain, snow, and gales on all of the Great Lakes, except Superior, and at Chicago, Ill., the wind reached a maximum velocity of 56 miles an hour from the northeast during the 16th, winds of gale force continuing nearly 24 hours.

At 9:30 p. m. of the 17th storm warnings were displayed on the Atlantic coast from Cape Hatteras to Boston, Mass., and strong winds occurred during the night of the 17th–18th.

On the morning of the 20th a disturbance of marked intensity was central over Kansas and northeast storm warnings were displayed at 10 a. m. on Lake Superior and the northern portions of Lakes Michigan and Huron. Special observations at 1 p. m. showing a further increase in the intensity of the disturbance, southeast warnings were ordered at 4 p. m for the southern portions of Lakes Michigan and Huron. At 10 p. m. the warnings were extended over western Lake Erie. The disturbance moved northeastward to the Upper Mississippi Valley with slowly decreasing intensity and winds of gale force occurred only over western Lake Superior. However, a secondary disturbance developed over the southern Plains States during the night of the 20th–21st and moved rapidly northeastward to Illinois where it was central at 8 a. m. of the 22d. Storm warnings were immediately ordered for all of the Great Lakes, except southern Lake Michigan, and at 9:30 p. m. were displayed on the eastern shore of southern Lake Michigan and on the Atlantic coast from Cape Hatteras to Portland, Me. At 10 a. m. of the 23d the warnings were extended northward to Eastport, Me. Strong winds occurred almost generally and verifying velocities were reached at a number of stations in the northern Lake region and along the Atlantic coast. The highest velocity reported was 52 miles an hour from the south at New York, N. Y.

A storm of marked intensity was central over the Plains States on the morning of the 24th, with lowest pressure 29.16 inches at Sioux City, Iowa, and northeast storm warnings were displayed at 10 a. m. on Lake Superior and extreme northern Lake Michigan. Gales occurred on Lake Superior as forecast. A secondary disturbance developed over the west Gulf States and moved rapidly northeastward to Illinois during the 25th, thence directly northward over Wisconsin and western Lake Superior, disappearing in the direction of Hudson Bay. Storm warnings were displayed on all of the Great Lakes, except extreme southern Lake Michigan, and winds of gale force occurred almost generally, except on Lake Ontario and eastern Lake Erie. The highest velocity reported was 56 miles an hour from the northwest at Duluth, Minn.

The last storm warnings of the month were displayed on the eastern Maine coast on the 30th, and they were fully verified.

Small craft warnings were displayed as follows:

16th and 21st: Bay St. Louis, Miss., to Cedar Keys, Fla.

17th: Jacksonville, Fla., to Cape Hatteras.

25th: Southern and central Lake Michigan.

Two general cool waves overspread the district during the month, with temperatures ranging from 10° to 25° below normal, and with frosts as far south as the east Gulf coast and extreme northern Florida. The first cool wave occurred during the 9th–11th and the second during the 17th–18th. Warnings of frost and freezing temperature were issued well in advance of their occurrence in the regions affected. Frost warnings were also issued for limited areas on the 1st and the 29th.—*Charles L. Mitchell.*

CHICAGO FORECAST DISTRICT.

The month of April in the Chicago forecast district was characterized by unusually warm weather, which prevailed throughout most of the month, modified to a marked degree by three cool periods; also by the movement across the district of five areas of low pressure of great intensity, accompanied by shifting gales and widespread precipitation. As a consequence it was an exceptionally windy month over most of the district.

The first disturbance appeared in the far Northwest on the 2d, but it had not reached its full development until the 4th, after passing southward to the Great Basin. It then moved directly eastward, and by the time it reached the central valleys on the 6th it began to lose some of its energy. Snow attended the movement of this storm in the Rocky Mountain region and Plains States, with a considerable fall in temperature and strong northerly winds. The snowfall in Wyoming and western Nebraska was unusually heavy. Live-stock warnings were sent to Montana, South Dakota, and western Nebraska on the 3d; to South Dakota and western Nebraska and Wyo-

ming on the 4th; and to South Dakota, western Nebraska, western Kansas, and Wyoming on the 5th.

On the morning of the 8th a cold, high area had developed over the Rocky Mountain region, and warnings either of frost or freezing temperature were issued on the 8th, 9th, and 10th to the Middle States, where vegetation had advanced sufficiently to be susceptible. By the morning of the 11th frost had advanced far beyond the eastern and southern limits of the Chicago district, causing great damage to fruit buds and bloom, which were abnormally advanced because of the previous high temperatures. Orchardists employed whatever protection was available to limit the damage, but few of them in the central area are provided with heaters.

On the morning of the 12th another disturbance had developed in the West, and this also moved directly eastward over the district, but its consequences were not as serious, as it was followed immediately by another disturbance.

The third one on the 15th appeared centered on the southeastern slope of the Rockies, and the characteristics of this storm were much the same as those of the first great disturbance of the month—snow and strong northerly winds and rapidly falling temperature. The snowfall, in fact, in the case of the third storm reached eastward across the middle Mississippi Valley and Great Lakes region, and it was exceptionally heavy in that area for the season of the year.

Live-stock warnings on the 14th were sent to stations in Wyoming and on the 15th to stations in Kansas and Nebraska; and warnings for frost or freezing temperature were issued on the 15th, 16th, 17th, and 18th for practically the same area covered by similar warnings earlier in the month. The damage done by this second freeze is considered most serious.

The fourth storm appeared over the Great Basin on the 19th, and this moved eastward across the Chicago district very slowly, accompanied by general precipitation, but as it was followed immediately by another disturbance much like the second one of the month, no damaging effects from freeze or wind resulted in any portion of this district, and no warnings seemed to be necessary.

The fifth one first appeared in the British Northwest on the 22d, but this did not reach its full development until the 24th, when it covered the Great Plains. It then seemed to lose some of its energy, but later redeveloped and by the 27th it had reached the upper Lake region and finally passed northeastward into Ontario.

Live-stock warnings were issued to points in Nebraska and southeast Wyoming on the 24th and warnings for either frost or freezing temperature on the 24th, 25th, 27th, 28th, and 29th for much the same area as covered by the two previous frost warnings; and by the morning of the 30th the frost area had again reached beyond the limits of the Chicago forecast district, although the temperatures did not fall nearly as low as during the previous frost.

The following communication from the official in charge at Cheyenne, Wyo., was received in connection with live-stock warnings of April 4:

> Perhaps it may be of interest to know that the Corridale Sheep Co. thanked the local office over the phone for the live-stock warning of April 4, 1921.
>
> They had a thousand high-bred ewes that were just beginning to lamb, and run sheep in both the Cheyenne and Laramie localities. The storm was more severe at Laramie, about 4 inches snow falling. To the westward of Laramie, over the southern Sweetwater district, reports indicate the falls ranged from 6 to 24 inches.
>
> He also stated that to-day, although clear, is hard on lambing, as the wind which is averaging about 32 miles an hour with a temperature slightly above freezing soon chills the new-born lambs.—*H. J. Cox.*

NEW ORLEANS FORECAST DISTRICT.

Storm warnings were issued for the Texas coast on April 10, 12, 14, 16, and 24, and verifying velocities occurred during all displays except that ordered on the 14th, when the highest wind velocities did not exceed 27 and 28 miles.

Small-craft warnings were displayed on the Texas coast on the 4th, 5th, 8th, 16th, 21st, and 24th, and were justified. No storm occurred without warnings.

Frost occurred in some part of the district on the 10th, 17th, 18th, and occurred generally over the interior of the district on the 11th and 19th, for all of which warnings were issued. No frost of any extent occurred without warnings.

Fire-weather warnings were issued for national forests in Arkansas and Oklahoma on the 4th.

A "norther" warning for the benefit of shipping in the vicinity of Tampico, Mexico, was issued on the 16th.—*I. M. Cline.*

DENVER FORECAST DISTRICT.

Several Alberta storms, all of which were attended by the development of secondary low-pressure systems in the Plateau region, dominated weather conditions during April. The weather of the month contrasted sharply with the mild and pleasant weather of the preceding months of 1921. The mean temperature was below the normal throughout the district, and there were frequent alternations of warm and cold periods.

On the morning of the 3d a low-pressure center of considerable intensity was over Nevada. Advices of strong winds were issued for the district, and cold-wave warnings were issued for western Utah on the evening of the 3d. Strong winds in localities were followed by a fall in temperature of 30° in western Utah, with readings as low as 24°. Warnings of freezing temperatures were issued on the 5th, 6th, 7th, 8th, and 9th for large areas in the district, following the eastward movement of the storm.

The warnings of the 5th advised that temperatures would be below the freezing point in the fruit valleys of western Colorado, those of the 6th considerably below, and those of the 7th considerably below in the fruit valleys of western Colorado and northwestern New Mexico. Temperatures ranging from 12° to 20° occurred in the fruit valleys mentioned on the mornings of the 7th 8th. On the evening of the 13th a storm of marked intensity was central in Utah. Warnings of strong winds were issued for Arizona and Utah, with rain turning to snow in Utah and northwestern Arizona, and much colder weather in Utah. Strong winds occurred in localities and were followed by rain turning to snow. The temperature fell 20° to 28° in Utah, with readings as low as 26° to 32°. Warnings of freezing temperature or temperature below the freezing point were issued for the fruit valleys of Colorado and northwest New Mexico on the mornings of the 14th, 15th, and 16th. The temperatures in western Colorado on the morning of the 16th ranged from 20° to 27°. The storm center was over southeastern Colorado on the morning of the 15th, with high pressure in the northern Plains States and eastern Montana. Live-stock warnings were issued for eastern Colorado. High winds and heavy snow occurred in central and parts of northeastern Colorado during the next 24 hours, with temperatures below the freezing point. Warnings of freezing temperature were also issued for Roswell, in the Pecos Valley, on the mornings of the 15th and 16th and temperature near freezing on the 17th. The official in charge at Roswell advised fruit interests at the substations on

the mornings of the 16th and 17th that temperatures of 28° to 30° would occur the following nights. The temperatures predicted were verified to the exact degree except at two substations on the morning of the 18th, where the temperature reached 26°. On the morning of the 23d the barometer was decidedly below the normal in Utah and the Rocky Mountain region. Warnings of stormy weather and freezing temperature were issued for western Utah. The temperature fell 10° to 34° within 24 hours and ranged from 14° to 32° in western Utah. On the morning of the 24th the barometer was still abnormally low in the central and eastern parts of the district and warnings of temperatures below the freezing point were issued for the fruit valleys of western Colorado and northwest New Mexico. The temperatures in the fruit valleys ranged from 22° to 30° the following morning. Warnings of freezing temperature or heavy frost were also issued for the fruit valleys on the mornings of the 25th, 26th, and 27th and were verified.—*Frederick W. Brist.*

SAN FRANCISCO FORECAST DISTRICT.

The month of April, 1921, in this district was marked by frequent and rapid changes in both weather and temperature. The storm movement was rapid and storms moving inland from the north Pacific entered the continent at a high latitude. Most of the storms after reaching British Columbia or Alberta moved southward between the Cascade-Sierra Nevada and Rocky Mountains to southern Nevada and Arizona and thence eastward. Very little rain fell in this district during the first part of the month, but in the latter part frequent rains occurred in the north Pacific States, while practically drought conditions continued in California and Nevada.

Storm warnings were ordered eight times and small-craft warnings three times, and were generally verified.

Live-stock warnings were issued for eastern Washington, eastern Oregon, Idaho, and Nevada nine times. It is believed that these warnings were entirely justified.

Warnings for heavy or killing frosts were issued four times for California, nine times for Washington, Oregon, Idaho, and Nevada and were generally verified.

On the morning of the 9th a forecast was sent to the official in charge at Spokane, Wash., for distribution to the orchardists in that section, reading "weather for the next two days favorable for spraying." This was the first attempt to make a forecast of this character for that district and it was fully verified.

A warm wave spread over California from the 26th to the 29th, reaching its crest on the 28th, when afternoon temperatures at many places reached within a few degrees of the highest previous April record.—*G. H. Willson.*

RIVERS AND FLOODS.

FLOODS DURING APRIL, 1921.

By H. C. FRANKENFIELD, Meteorologist.

[Weather Bureau, Washington, D. C., June 1, 1921.]

ATLANTIC DRAINAGE.

Floods were quite numerous during the month of April, although none was of very marked character.

The Connecticut River was in flood at White River Junction, Vt., at the close of March, and a heavy rain on April 1 caused another rise which continued down the river, causing a crest of 16.9 feet, or 0.9 foot above the flood stage, at Hartford, Conn., at 1 a. m. April 3. No damage was done.

EAST GULF DRAINAGE.

The Apalachicola River was two feet above the flood stage of 12 feet at River Junction, Fla., on April 19 and 20, but no damage was reported.

Heavy rains on April 14 caused brief and moderate rises in the Cahaba and Upper Alabama Rivers, and another heavier rain two days later caused general and decided rises in all the rivers of the Alabama system. Warnings were issued on April 16 and 17. The crest stages were as follows: Cahaba River at Centerville, Ala., 31 feet or 6 feet above the flood stage; Tallapoosa River at Milstead, Ala., 24.1 feet (forecast stage, 26 feet), and Alabama River at Montgomery and Selma, Ala., 30.0 and 36.1 feet, respectively, flood stage being at 35 feet. Loss and damage amounted to less than $20,000.

A moderate flood in the Tombigbee River in the vicinity of Demopolis, Ala., necessitated warnings on April 2 and 4, with flood stages beginning on April 4, and a crest stage of 41.4 feet, or 2.4 feet above the flood stage occurred on April 5. The river was above the flood stage from April 4 to 7, inclusive.

The heavy rains of the middle of the month caused a severe flood over the entire Tombigbee watershed, and warnings of high flood stages in the Black Warrior and Tombigbee Rivers were issued on April 16 and 17, the rise in the latter river to continue for about one week. The crest stages were as follows: Black Warrior River at Tuscaloosa, Ala., 56.0, 10 feet above flood stage, and Tombigbee River at Aberdeen, Miss., 35.1 feet, flood stage being at 33 feet. The flood continued in the lower river until May 6, with a crest stage of 51.8 feet at Demopolis, Ala., on May 1. The resulting damage amounted to more than $100,000.

The floods in the Pascagoula and Pearl systems were very severe, and were excellently forecast by the official in charge of the district, Mr. J. H. Jaqua of Meridian, Miss., who has compiled a detailed report that has been filed at the central office of the Weather Bureau. Stages approximating those of highest record were reached, and the amount of damage and losses propably exceeded $1,000,000, of which more than one half was in bridges, roads, etc.

MISSISSIPPI DRAINAGE.

The tide in the Tennessee River and tributaries was more moderate in so far as flood stages were concerned, although there were rapid and decided rises that called for flood warnings on April 17 and 18. At Chattanooga, Tenn., the crest stage in the Tennessee River was 29.2 feet, 3.8 feet below the flood stage, at 4.20 p. m., April 18. The public had been advised that the flood stage would not be reached. At Florence and Riverton, Ala., the flood stages were reached as forecast, and accurate forecasts were also made for points below. The damage done was quite small.

A warning issued at Cairo, Ill., on the morning of April 1 for slightly over the flood stage of 35 feet in the Ohio River at Shawneetown, Ill., was followed six days later by a crest stage of 34.8 feet.

The late March floods in the White River of Indiana and the Wabash River continued during the early days of April and flood stages were quite general with a crest of 22.1 feet or 7.1 feet above the flood stage in the Wabash River at Mount Carmel, Ill., on April 5. Warnings for the flood were issued at the proper times, and the damage and losses amounted to about $12,000. Value of property saved through warnings, about $25,000.

A slow rise began in the Illinois River on April 22 and continued for slightly more than one week. Flood stages were general but only moderate, and warnings were issued accordingly. At the end of the month the river was still rising slowly from Henry to Beardstown, Ill. Some inconvenience, but no damage resulted.

A moderate flood in the upper Wisconsin River during the closing days of the month caused considerable damage to crops and some road damage in the vicinity of Knowlton, Wis. Warnings were issued on April 27.

There were also floods in the Meramec, Gasconade and Osage Rivers of Missouri at the end of the month. The Meramec flood was quite pronounced on account of the heavy rains of April 26 and 27, and all low bottoms below Moselle, Mo., were flooded. Warnings were issued on April 26, 27, and 28. There was little or no damage, as the warnings enabled the various industries affected to take necessary precautions.

The same general rain conditions caused a flood in the Arkansas River and tributaries, and accurate warnings were issued on April 26 and 27. Flood stages were general with a maximum rise in the upper White River. The lower White River remained at moderately high stage throughout the month, and there was a break in the White River Levee just above Georgetown, Ark., necessitating a revision of forecast stages below that place. Losses amounted to about $273,000.

The Tallahatchie and Yazoo Rivers were still in flood at the close of the month, and estimate of losses will be given later.

The Arkansas River flood caused flood stages in the Mississippi River in the vicinity of Arkansas City, Ark., and the river was generally above the flood stage of 42 feet after April 4, with a crest stage of 45.3 feet from April 14 to 16, inclusive.

Warnings for the floods in the Ouachita and upper Atchafalaya floods were issued on April 23 and 26, and at the end of the month the latter river was slightly above the flood stage of 37 feet at Melville, La., and still rising.

The floods also extended over the Little, Sulphur, and Cypress Rivers, tributaries of the Red River, and warnings were issued on April 26 for the entire Red River watershed as far as Springbank, Ark. The warnings were well justified by the subsequent occurrences. Loss and damage amounted to about $165,000.

WEST GULF DRAINAGE.

There were two floods in the Sabine River, one from April 11 to 14 inclusive, and another from April 27 until after the close of the month. At Logansport, La., the crest stage was 36.8 feet, or 11.8 feet above the flood stage on April 28 and 29, and moderate flood stages also prevailed along the lower river. Warning was issued on April 26. Damage amounted to about $60,000.

There were no flood stages reached in the Brazos River, but quite high stages prevailed in the Trinity River for which warnings were issued at the proper times. Crest stages were several feet above the flood stages as a rule, and the damage done amounted to about $220,000.

There was a sharp rise in the lower Colorado River on April 7 and 8, but no damage was done.

The Guadalupe River was in flood from heavy rains over the San Marcos Basin, beginning with April 9 at Gonzales, Tex., and ending with April 13 at Victoria, Tex. Damage was only nominal, but much property mainly in the shape of livestock, was saved by removal to places of safety.

Estimated losses by flood during April, 1921.

Rivers of—	Tangible property, bridges, roads, buildings, etc.	Estimated loss of crops.		Live stock or other farm property.	Suspension of business.	Value of warnings.[1]
		Matured.	Prospective.			
Alabama	$5,400	$6,000	$125,700	$1,500	$3,900	$5,300
Mississippi	500,000	140,000	100,000	10,000	50,000	23,300
Indiana	1,200	1,000	10,000	....	2,500	25,000
Arkansas	74,000	....	180,000	5,000	14,000	....
Louisiana and Texas	135,000	....	246,000	25,000	50,000	....
Total	715,600	147,000	661,700	41,500	120,400	53,600

[1] Does not include value of large numbers of live stock removed to places of safety.

Flood stages during month of April, 1921.

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
ATLANTIC DRAINAGE.					
Connecticut:	*Feet.*			*Feet.*	
White River Junc., Vt	13	(*)	2	14.0	1
Hartford, Conn	16	2	3	16.9	3
EAST GULF DRAINAGE.					
Apalachicola:					
River Junc., Fla	12	18	21	14.0	19, 20
Alabama:					
Selma, Ala	35	20	21	36.1	20
Cahaba:					
Centerville, Ala	25	16	17	31.0	17
Tombigbee:					
Aberdeen, Miss	33	19	20	35.1	19
Demopolis, Ala	39	4	7	41.4	5
	39	17	(**)	54.9	25
Black Warrior:					
Tuscaloosa, Ala	46	17	20	56.0	18
Pascagoula:					
Merrill, Miss	20	19	25	22.9	21
Chickasawhay:					
Enterprise, Miss	21	17	19	31.8	18
Shubuta, Miss	27	17	22	34.6	20
Leaf:					
Hattiesburg, Miss	19	17	20	25.0	17
Pearl:					
Jackson, Miss	20	2	(**)	32.9	21, 22
Columbia, Miss	18	15	(**)	25.3	30
West Pearl:					
Pearl River, La	13	10	(**)	16.9	20
GREAT LAKES DRAINAGE.					
Pine:					
Alma, Mich	6	23	23	6.0	23
Chippewa:					
Mount Pleasant, Mich	12	24	27	12.6	26

* Continued from March. ** Continued into May.

Flood stages during month of April, 1921—Continued.

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
MISSISSIPPI DRAINAGE.					
Tuscarawas:	*Feet.*			*Feet.*	
Norris Point, Ohio	8	(*)	1	8.9	1
Coshocton, Ohio	8	(*)	1	8.4	1
Wabash:					
Lafayette, Ind	11	(*)	1	11.1	1
Terre Haute, Ind	16	(*)	4	17.5	2
Vincennes, Ind	14	(*)	7	15.7	6
Mount Carmel, Ill	15	(*)	9	22.1	5
White:					
East Fork—					
Decker, Ind	18	(*)	7	22.7	4
Williams, Ind	10	(*)	2	11.7	2
West Fork—					
Shoals, Ind	20	(*)	3	22.4	2
Elliston, Ind	19	(*)	3	25.0	1
New:					
New River, Tenn	25	16	16	25.0	16
French Broad:					
Penrose, N. C	13	17	17	13.9	17
Asheville, N. C	4	17	17	4.3	17
Tennessee:					
Florence, Ala	18	19	19	18.0	19
Riverton, Ala	32	18	22	36.4	19
Wisconsin:					
Knowlton, Wis	12	29	29	15.5	29
Illinois:					
Peru, Ill	14	25	(**)	15.2	28
Henry, Ill	7	24	(**)	9.1	30
Peoria, Ill	16	30	(**)	16.0	30
Pearl, Ill	12	29	(**)	12.2	29, 30
Beardstown, Ill	12	25	(**)	13.8	30
Gasconade:					
Arlington, Mo	12	28	29	13.8	28
Meramec:					
Pacific, Mo	11	27	(**)	19.4	29
Valley Park, Mo	14	28	(**)	23.5	29
Bourbeuse:					
Union, Mo	10	27	29	15.1	28
St. Francis:					
Marked Tree, Ark	17	13	27	17.4	15, 18, 25
Mississippi:					
Arkansas City, Ark	42	5	(**)	45.3	14-16
Yazoo:					
Greenwood, Miss	36	23	(**)	37.3	27, 28
Yazoo City, Miss	25	14	(**)	30.6	30
Tallahatchie:					
Swan Lake, Miss	25	(*)	(**)	29.8	25-27
Ouachita:					
Arkadelphia, Ark	18	27	28	21.3	27
Camden, Ark	30	28	(**)	38.1	30
Atachafalya:					
Melville, La	37	23	(**)	37.3	28-30
Petit Jean:					
Danville, Ark	20	26	(**)	24.6	28
White:					
Calico Rock, Ark	18	26	(**)	34.6	27
Batesville, Ark	23	(*)	1	23.1	1
	23	27	(**)	36.4	28
Newport, Ark	26	(*)	3	28.5	1
	26	28	(**)	31.3	30
Georgetown, Ark	22	(*)	12	26.0	3
	22	28	(**)	24.9	30
Clarendon, Ark	30	6	9	30.2	8
Black:					
Black Rock, Ark	14	(*)	13	20.0	1
	14	24	(**)	25.0	28
Cache:					
Patterson, Ark	9	(*)	19	9.7	18
	9	28	(**)	9.1	28, 29
Little:					
Whitecliffs, Ark	28	28	29	29.0	28
Sulphur:					
Finley, Tex	24	28	(**)	25.9	29
Ringo Crossing, Tex	20	15	18	23.0	17
	20	24	26	23.0	25
Cypress:					
Jefferson, Tex	18	27	28	19.0	27
WEST GULF DRAINAGE.					
Trinity:					
Dallas, Tex	25	6	10	ϕ 34.7	7
Trinidad, Tex	28	13	17	33.2	16
Liberty, Tex	25	12	(**)	27.2	29, 30
Sabine:					
Logansport, La	25	11	14	26.5	12
	25	28	(**)	36.8	29
Neches:					
Rockland, Tex	20	14	19	22.5	16
	20	23	27	21.0	25
Guadalupe:					
Gonzales, Tex	22	9	10	20.7	9
Victoria, Tex	16	11	13	19.6	13

* Continued from March
** Continued into May.
ϕ Estimated.

MEAN LAKE LEVELS DURING FEBRUARY, 1921.

By UNITED STATES LAKE SURVEY.

[Detroit, Mich., Mar. 3, 1921.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.*			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during February, 1921:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	601.76	579.84	571.85	245.46
Above or below—				
Mean stage of January, 1921	−0.32	−0.08	−0.14	−0.08
Mean stage of February, 1920	−0.14	−0.14	+1.07	+0.45
Average stage for February, last 10 years	−0.07	−0.11	+0.29	−0.01
Highest recorded February stage	−0.72	−2.88	−1.90	−2.21
Lowest recorded February stage	+1.00	+0.68	+1.22	+1.63
Average relation of the February level to:				
January level		0.00	−0.10	+0.10
March level		−0.10	−0.10	−0.10

* Lake St. Clair's level: In February, 573.52 feet.

MEAN LAKE LEVELS DURING MARCH, 1921.

By UNITED STATES LAKE SURVEY.

[Detroit, Mich., Apr. 4, 1921.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.*			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during March, 1921:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	601.55	579.90	572.14	245.79
Above or below—				
Mean stage of	−0.21	+0.06	+0.29	+0.33
Do	−0.33	−0.19	+1.29	+0.74
Average stage for March, last 10 years.	−0.13	−0.10	+0.47	+0.19
Highest recorded stage	−0.73	−3.05	−1.71	−2.02
Lowest recorded stage	+0.89	+0.79	+1.31	+1.49
Average relation of the March level to:				
February level		+0.10	+0.10	+0.10
April level		−0.30	−0.70	−0.70

* Lake St. Clair's level: In March, 574.74 feet.

MEAN LAKE LEVELS DURING APRIL, 1921.

By UNITED STATES LAKE SURVEY.

[Detroit, Mich., May 4, 1921.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.*			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during April, 1921:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	601.69	580.34	572.79	246.38
Above or below—				
Mean stage of March, 1921	+0.14	+0.44	+0.67	+0.59
Mean stage of April, 1920	−0.52	−0.20	+1.17	+0.83
Average stage for April, last 10 years.	−0.01	+0.05	+0.44	+0.06
Highest recorded April stage	−1.00	−2.89	−1.39	−2.05
Lowest recorded April stage	+1.15	+1.12	+1.53	+1.54
Average relation of the April level to:				
March level		+0.30	+0.70	+0.70
May level		−0.30	−0.40	−0.30

* Lake St. Clair's level: In April, 575.41 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, APRIL, 1921.

By J. WARREN SMITH, Meteorologist.

The weather during April was mostly unfavorable for farming operations. While the moisture was sufficient generally, except in the Southeast and Southwest, cool waves were frequent and there was too much rainfall in many Central and Southern States to permit of satisfactory progress in spring work. Frosts and freezing temperatures on several occasions during the month extended considerably the area in which severe damage was done to fruit by the cold wave near the close of March. Considerable damage was done to fruit in California and Oregon during the week ending April 12, while heavy damage was reported from the former State during that ending the 19th.

The ample soil moisture in most sections of the country permitted of satisfactory development of the hardier grains and grasses, although growth was checked by the frequent cool waves. It was too cool for the proper growth of corn during much of the month in the Southern States, and there was considerable delay in the preparation of the soil for this crop by reason of frequent rains and wet soil in most central districts. At the close of the month corn planting was behind the average in the central Great Plains States and in the Mississippi and Ohio Valleys.

Cotton planting made fairly good progress in the more Eastern States of the belt where precipitation was light, but this work was greatly hindered in the central and in much of the western portions of the belt by frequent rains. Germination was slow and unsatisfactory in most sections of the belt and considerable replanting was necessary. From 6 to 12 inches of rain occurred during the month in much of the belt.

There was sufficient moisture for the growth of grass on meadows, pastures, and ranges, except in the Southeastern and Southwestern States, but it was too cool for alfalfa in the Northwest. Stock continued mostly in satisfactory condition, except in parts of New Mexico and Arizona, where the range was very poor on account of drought, and some loss of stock was reported. There was considerable precipitation in the central and northern Rocky Mountain sections, which was beneficial to ranges in that area, but the cold weather and heavy snows in the central Rocky Mountain districts were rather unfavorable for stock, although no serious losses were reported.

CLIMATOLOGICAL TABLES.*

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, April, 1921.

Section.	Temperature.		Monthly extremes.						Precipitation.		Greatest monthly.		Least monthly.	
	Section average.	Departure from the normal.	Station.	Highest.	Date.	Station.	Lowest.	Date.	Section average.	Departure from the normal.	Station.	Amount.	Station.	Amount.
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	62.3	−0.8	5 stations	88	25†	Valley Head	27	10	6.55	+2.05	Healing Springs	10.87	Spring Hill	2.10
Arizona	57.6	−1.6	Mohawk	107	30	Spring Valley	4	7	0.35	−0.20	Cosnino	1.95	7 stations	0.00
Arkansas	59.8	−1.1	Huttig	91	27	Nail	22	17	7.87	+3.02	Conway	12.52	Bentonville	4.54
California	55.0	−2.0	Needles	104	29	Fordyce Dam	2	15	0.57	−1.22	Helen Mine	6.59	15 stations	0.00
Colorado	40.6	−2.3	Burlington	92	3	2 stations	−14	8†	2.64	+0.72	Silver Lake	15.16	2 stations	0.13
Florida	70.3	+0.4	4 stations	94	9†	Garniers (near)	30	12	2.03	−0.58	Bonifay	8.61	Long Key	0.07
Georgia	63.6	+0.2	Glennville	92	26	Blue Ridge	24	12	3.34	−0.22	Blakely	10.68	Augusta	1.25
Hawaii (March)	69.7	+0.9	Kapoho	94	9	Waimea	40	1†	4.52	−3.69	Waiakamoi	21.88	Waiawa	0.00
Idaho	42.3	−2.9	Murphy	83	2	Stanley	−10	8	1.91	+0.38	Orofino	4.64	Glenns Ferry	0.20
Illinois	55.6	+3.9	Mount Carmel	86	25	4 stations	22	10†	4.81	+1.39	Aledo	6.76	Hoopeston	0.62
Indiana	55.6	+3.9	4 stations	88	5†	Shelbyville	20	11	4.28	+0.81	Salamonia	6.63	Terre Haute	1.97
Iowa	52.4	+3.7	2 stations	88	24	2 stations	14	16†	3.34	+0.48	Mount Pleasant	6.99	Sioux City	0.99
Kansas	54.9	+0.9	Ashland	93	24	St. Francis	10	10	3.12	+0.72	Fort Scott	7.87	Elkhart	1.02
Kentucky	58.2	+2.3	2 stations	90	26†	Shelbyville	22	11	4.09	+0.15	Bowling Green	5.59	Richmond	2.21
Louisiana	65.6	−1.2	2 stations	90	23†	3 stations	30	11†	6.77	+1.77	Simmesport	11.35	Burrwood	1.35
Maryland-Delaware	58.1	+5.5	3 stations	92	25	Grantsville, Md	16	11	3.18	−0.18	Milford, Del	4.79	Friendsville, Md	1.85
Michigan	48.7	+6.3	Petosky	87	25	West Branch	6	1	3.49	+1.15	Edmore	6.14	Grand Marais	0.82
Minnesota	46.8	+4.0	Montevideo	87	24	Red Lake	4	1	1.80	−0.29	St. Charles	3.93	Faribault	0.18
Mississippi	62.8	−1.3	2 stations	90	25†	Pontotoc	30	16†	9.35	+4.09	Greenwood	15.13	Pasagoula	2.56
Missouri	56.0	+0.9	Caruthersville	91	25	Maryville	19	17	5.37	+1.52	Arcadia	8.42	Conception	1.86
Montana	41.2	−1.1	Melstone	83	3	Bowen	−7	7	1.24	+0.13	Adel	4.55	Harlowton	0.00
Nebraska	49.8	+1.0	Tekamah	94	4	2 stations	5	7†	1.94	−0.53	Guide Rock	5.22	Bridgeport	0.34
Nevada	46.6	−1.8	Logandale	96	28	Millett	7	7	0.56	−0.09	Mahoney Ranger Sta.	2.91	4 stations	0.00
New England	49.0	+5.6	Vernon, Vt	92	26	Van Buren, Me	−3	7	3.95	+0.77	Rutland, Mass	7.74	Bennington, Vt	1.92
New Jersey	56.3	+6.8	Moorestown	87	25	Culvers Lake	15	2	3.57	−0.11	Long Branch	5.20	Trenton	1.86
New Mexico	48.7	−2.4	2 stations	92	30	Red River Canyon	−6	16	0.25	−0.85	Red River Canyon	3.24	29 stations	0.00
New York	51.9	+7.6	2 stations	91	26	Lake Placid Club	8	11	3.25	+0.45	Mohonk Lake	6.20	Moira	1.23
North Carolina	60.0	+2.6	2 stations	92	25†	Banners Elk	17	12	4.03	+0.51	Rock House	6.86	Henderson	1.23
North Dakota	41.1	−0.6	Edgeley	91	3	Willow City	1	8	1.81	+0.43	Ashley	4.72	Hettinger	0.27
Ohio	55.1	+5.3	Middleport	93	25	2 stations	18	11	3.90	+0.67	Benton Ridge	7.11	Tiltonville	1.72
Oklahoma	59.1	−0.7	Frederick	96	23	Goodwell	13	10	3.76	+0.18	Broken Arrow	8.87	Kenton	0.75
Oregon	46.6	−1.4	Blitzen	89	1	Lapine	1	4	2.30	+0.19	Government Camp	11.12	Reservoir No. 3	0.05
Pennsylvania	55.3	+6.7	Everett	96	26	Mount Pocono	10	1	3.11	−0.23	Corry	5.06	Neshaming Falls	1.12
Porto Rico														
South Carolina	63.3	+1.0	2 stations	91	26	Santuck	27	12	2.43	−0.48	Conway	4.46	Blackville	0.95
South Dakota	47.2	+2.4	Pollock	95	3	2 stations	6	9†	1.49	−0.34	Faulkton	5.62	Bellefouche	0.20
Tennessee	59.3	+0.9	4 stations	89	25	Mountain City	16	12	5.16	+0.46	Memphis	11.64	Jefferson City	2.20
Texas	64.3	−1.8	Encinal	105	25	Dalhart	18	10	3.68	+0.46	Marshall	16.20	2 stations	0.00
Utah	43.9	−3.1	St. George	91	29	Black's Fork	−9	7	1.83	+0.71	Farmington	4.96	Esclante	0.00
Virginia	59.1	+4.7	Mayhurst	95	25†	Burkes Garden	13	12	2.99	−0.44	Onley	5.65	Catawba Sanatorium	1.10
Washington	46.4	−2.2	Landsburg	80	10	Paradise Inn	11	4	2.55	+0.49	Cedar Lake	12.75	Wenatchee	0.10
West Virginia	55.7	+4.1	Logan	95	26	Marlinton	10	12	2.50	−1.00	Green Sulphur Springs.	5.09	Upper Tract	0.40
Wisconsin	49.0	+5.1	Ashland	91	24	Winter	9	10	4.32	+1.98	Williams Bay	7.95	Hayward	1.29
Wyoming	38.3	−2.6	Echeta	82	3	Riverside	−12	24	1.36	−0.19	Bow Ranger	6.90	Hyattville	0.00

* For description of tables and charts, see Review for January, 1921, p. 41.

† Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, April, 1921.*

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation: Thermometer above ground.	Elevation: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature: Mean max.+mean min.÷2.	Temperature: Departure from normal.	Temperature: Maximum.	Temperature: Date.	Temperature: Mean maximum.	Temperature: Minimum.	Temperature: Date.	Temperature: Mean minimum.	Temperature: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 inch or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Maximum velocity: Direction.	Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
New England.							**48.9**	**+ 5.3**										**80**	**3.55**	**+ 0.5**										**6.4**		
Eastport	76	67	85	30.00	30.09	+ .16	41.8	+ 3.5	76	28	48	26	2	35	29	38	36	85	2.98	0.0	14	8,725	s.	48	nw.	3	7	8	15	6.7	4.5	0.0
Greenville, Me.	1,070	6																														
Portland, Me.	103	82	117	29.97	30.10	+ .14	46.1	+ 3.1	69	21	53	30	2	39	26	42	37	75	3.41	+ 0.3	11	6,911	n.	30	nw.	3	8	8	14	6.5	T.	0.0
Concord	288	70	79	29.76	30.07	+ .08	49.4	+ 5.6	83	5	61	23	2	38	50				4.27	+ 1.5	12	3,695	se.	26	nw.	21	10	7	13	6.0	0.3	0.0
Burlington	404	11	48	29.62	30.06	+ .07	47.2	+ 6.5	77	29	58	21	11	37	38				2.98	+ 1.1	8	8,086	n.	48	s.	8	8	9	13	6.0	0.3	0.0
Northfield	876	12	60	29.11	30.07	+ .08	46.4	+ 6.2	79	6	59	18	2	34	43	42	37	73	2.29	+ 0.2	11	6,053	s.	34	sw.	21	6	12	12	6.4	0.3	0.0
Boston	125	115	188	29.92	30.06	+ .09	51.8	+ 6.5	77	9	60	32	2	44	33	46	42	76	4.62	+ 1.1	14	6,973	e.	28	n.	11	8	9	13	6.5	T.	0.0
Nantucket	12	14	90	30.03	30.04		48.4	+ 4.2	66	5	54	35	11	43	23	46	45	92	2.49	− 0.2	15	13,626	sw.	49	n.	11	7	6	17	7.1	T.	0.0
Block Island	26	11	46	30.02	30.05	+ .07	48.5	+ 4.7	64	22	54	32	11	43	22	46	45	92	2.76	− 0.9	11	12,402	sw.	46	ne.	11	9	3	18	6.7	0.5	0.0
Providence	160	215	251	29.88	30.05	+ .07	51.3	+ 4.7	82	5	61	32	2	42	42	46	41	77	4.21	+ 0.4	14	8,384	ne.	44	nw.	9	7	6	17	6.9	T.	0.0
Hartford	159	122	140	29.88	30.05	+ .06	53.6	+ 6.9	82	5	64	31	11	43	36	47	42	70	4.07	+ 0.5	12	5,661	s.	31	se.	23	9	6	15	6.2	T.	0.0
New Haven	106	74	153	29.94	30.05	+ .06	53.3	+ 6.9	79	5	63	30	11	44	31	48	45	80	4.98	+ 1.4	14	6,732	ne.	31	se.	23	9	8	13	5.7	T.	0.0
Middle Atlantic States.							**56.5**	**+ 5.8**										**72**	**3.04**	**0.0**										**5.6**		
Albany	97	102	115	29.94	30.04	+ .04	53.2	+ 7.4	82	6	64	27	11	43	37	47	42	70	2.65	+ 0.3	12	5,848	s.	40	se.	23	15	7	8	4.3	T.	0.0
Binghamton	871	10	84	29.10	30.04	+ .02	53.8	+ 9.4	86	26	66	22	2	42	44				3.04	+ 0.8	13	4,236	ne.	24	se.	23	10	5	15	5.8	6.4	0.0
New York	314	414	454	29.70	30.04	+ .04	55.0	+ 6.9	76	4	64	28	11	46	28	49	44	74	2.88	− 0.4	12	11,349	sw.	53	se.	23	9	8	13	6.1	0.1	0.0
Harrisburg	374	94	104	29.65	30.05	+ .03	56.9	+ 6.2	87	25	67	28	11	47	33	50	43	65	3.29	+ 0.8	12	3,446	s.	22	nw.	9	9	8	13	6.0	T.	0.0
Philadelphia	117	123	190	29.94	30.07	+ .06	58.5	+ 7.7	82	25	68	29	11	48	28	52	49	77	1.8[illegible]	− 1.1	12	7,662	s.	33	s.	23	10	4	16	6.0	0.4	0.0
Reading	325	81	98	29.70	30.05		57.2		85	25	67	28	11	47	33	50	44	65	5.76	+ 2.5	13	4,440	se.	25	se.	23	10	6	14	5.8	0.1	0.0
Scranton	805	111	119	29.18	30.04	+ .03	55.6	+ 8.5	89	26	67	25	2	44	35	49	43	70	2.88	+ 0.2	11	4,958	nw.	26	se.	14	13	7	10	5.1	3.0	0.0
Atlantic City	52	37	48	30.00	30.06	+ .06	52.9	+ 5.3	73	24	59	30	2	47	27	49	47	83	3.16	+ 0.2	13	5,942	sw.	23	se.	23	11	4	15	5.6	1.4	0.0
Cape May	18	13	49	30.07	30.09	+ .10	53.8	+ 5.4	73	24	60	29	11	48	22	50	48	85	2.97	0.0	14	7,046	s.	36	s.	23	9	4	17	6.2	2.1	0.0
Sandy Hook	22	10	55	30.03	30.05		54.0		75	4	62	31	11	46	28	49	47	84	2.21		11	10,046	s.	54	nw.	17	9	8	13	6.2	T.	0.0
Trenton	190	159	183	29.84	30.04		56.6		80	25	67	29	2	46	30	51	47	76	1.86	− 1.4	13	7,896	sw.	49	se.	23	10	6	14	6.0	0.2	0.0
Baltimore	123	100	113	29.93	30.06	+ .05	58.6	+ 5.6	83	25	68	31	11	49	30	52	46	66	2.59	− 0.7	13	4,667	s.	26	s.	22	10	9	11	5.7	T.	0.0
Washington	112	62	85	29.93	30.06	+ .04	59.2	+ 6.1	90	25	70	31	11	48	38	51	45	64	2.93	− 0.3	12	5,359	s.	30	nw.	17	10	3	17	6.2	T.	0.0
Lynchburg	681	153	188	29.32	30.07	+ .05	59.1	+ 3.5	91	26	71	28	11	47	40	53	48	72	2.76	− 0.4	13	6,649	sw.	33	n.	10	12	12	6	4.6	0.0	0.0
Norfolk	91	170	205	29.98	30.08	+ .07	61.2	+ 5.2	88	25	71	34	11	52	28	54	49	72	3.02	− 0.8	8	10,097	s.	40	s.	23	7	12	11	5.7	0.0	0.0
Richmond	144	11	52	29.92	30.08	+ .06	60.1	+ 2.9	88	25	71	33	11	49	36	53	47	69	4.65	+ 1.2	11	6,303	s.	33	nw.	17	11	4	15	5.6	T.	0.0
Wytheville	2,304	49	56	27.71	30.09	+ .06	53.4	+ 1.4	83	26	64	23	11	43	37	46	41	68	2.38	− 1.3	11	5,008	nw.	32	w.	17	14	5	11	4.6	T.	0.0
South Atlantic States.							**63.3**	**+ 2.1**										**68**	**2.43**	**− 0.9**										**4.9**		
Asheville	2,255	70	84	27.74	30.09	+ .06	55.2	+ 1.3	83	26	66	28	11	44	37	47	41	64	2.97	− 1.1	8	7,556	se.	39	e.	16	13	9	8	4.5	T.	0.0
Charlotte	779	55	62	29.24	30.08	+ .05	61.6	+ 2.4	86	26	72	34	12	51	31	53	46	63	1.99	− 1.4	8	4,187	s.	23	sw.	17	12	8	10	5.0	0.0	0.0
Hatteras	11	12	50	30.06	30.07	+ .06	62.4	+ 4.4	78	26	69	41	11	56	24	58	56	80	4.85	+ 0.4	10	11,186	sw.	50	nw.	10	8	8	14	5.9	0.0	0.0
Manteo	12	5	42																													
Raleigh	376	103	110	29.67	30.08	+ .05	61.4	+ 2.4	87	26	72	35	11	51	32	53	46	63	2.12	− 1.4	10	6,613	sw.	32	se.	22	9	14	17	6.0	0.0	0.0
Wilmington	78	81	91	30.01	30.09	+ .06	63.4	+ 3.0	85	25	72	36	11	55	30	58	54	75	4.94	+ 2.1	14	6,492	s.	37	sw.	17	10	11	9	5.0	0.0	0.0
Charleston	48	11	92	30.03	30.08	+ .05	66.3	+ 2.5	86	27	74	42	11	59	23	60	55	72	2.06	− 0.9	9	8,308	s.	42	se.	22	11	10	9	5.0	0.0	0.0
Columbia, S. C.	351	41	57	29.71	30.09	+ .06	64.2	+ 1.4	86	26	75	37	11	54	31	55	49	64	1.24	− 1.6	7	5,270	s.	28	sw.	22	13	7	10	4.6	0.0	0.0
Greenville, S. C.	1,039	113	122	28.97	30.07		61.0		83	26	71	36	11	51	29	52	45	61	2.85		10	6,380	sw.	50	sw.	16	16	9	5	4.0	0.0	0.0
Augusta	180	62	77	29.89	30.08	+ .05	64.5	+ 1.3	86	9	77	36	12	52	35	57	52	69	1.25	− 2.2	5	4,498	nw.	36	nw.	16	9	14	8	5.1	0.0	0.0
Savannah	65	150	194	30.02	30.09	+ .06	66.6	+ 1.9	85	9	76	42	11	58	28	58	53	68	1.68	− 1.3	5	9,198	s.	58	se.	17	11	11	8	4.6	0.0	0.0
Jacksonville	43	209	245	30.04	30.09	+ .05	67.8	+ 0.2	86	26	76	43	18	60	21	61	57	74	1.23	− 1.5	5	9,434	se.	42	se.	14	13	12	5	4.1	0.0	0.0
Due West	711	10	55	29.34	30.11		61.4		85	26	73	32	11	50	32				1.65		8	6,289	s.	40	nw.	16	13	10	7	4.6	0.0	0.0
Florida Peninsula.							**74.4**	**+ 0.8**										**70**	**1.73**	**− 0.2**										**3.9**		
Key West	22	10	64	30.02	30.04	+ .02	77.2	+ 1.7	85	23	82	65	19	72	15	69	66	71	0.47	− 0.8	3	8,898	se.	27	e.	13	18	11	1	3.1	0.0	0.0
Miami	25	71	79	30.04	30.07		74.0	− 0.2	88	23	80	52	12	68	23	67	64	71	2.63	0.0	5	7,139	e.	25	s.	23	11	12	7	4.8	0.0	0.0
Sand Key	23	39	72	29.99	30.02	.00	75.4		83	10	78	64	19	73	10	69	66	73	0.39		1	12,160	e.	38	se	14	19	9	2	3.1	0.0	0.0
Tampa	35	79	92	30.04	30.08	+ .02	71.9	+ 0.9	89	25	82	46	12	62	30	63	58	67	2.08	+ 0.2	4	5,483	ne.	21	s.	23	13	9	8	4.5	0.0	0.0
East Gulf States.							**63.8**	**− 0.8**										**69**	**5.17**	**+ 1.1**										**4.6**		
Atlanta	1,174	190	216	28.86	30.10	+ .07	61.0	− 0.1	83	26	71	34	11	51	30	53	46	64	3.31	− 0.3	5	8,791	nw.	36	nw.	10	12	8	10	4.6	0.0	0.0
Leesburg	279	10	55																													
Macon	370	78	87	29.70	30.09	+ .06	62.9	− 0.2	86	26	75	33	12	51	38	55	49	64	2.58	− 0.8	5	5,291	nw.	32	nw.	16	13	9	8	4.3	0.0	0.0
Thomasville	273	49	58	29.78	30.08	+ .05	66.4	− 0.3	88	25	77	40	11	56	33	57	51	65	3.09	− 0.6	5	3,459	sw.	27	s.	22	12	9	9	4.7	0.0	0.0
Pensacola	56	149	185	30.02	30.08	+ .06	65.0	− 2.7	82	9	71	40	18	59	28	60	56	74	4.45	+ 1.3	8	11,242	n.	54	s.	14	10	9	11	5.4	0.0	0.0
Anniston	741	9	57	29.31	30.11	+ .08	60.6	+ 0.2	85	25	73	32	12	48	36				4.65	+ 1.0	6	4,612	se.	23	nw.	10	13	12	5	3.9	0.0	0.0
Birmingham	700	11	48	29.34	30.10	+ .08	62.6	− 1.1	85	25	74	34	11	51	36	53	47	65	4.81	+ 1.1	6	5,793	s.	48	sw	16	14	11	5	4.2	0.0	0.0
Mobile	57	125	161	30.01	30.07	+ .05	65.8	− 0.2	83	8	74	40	18	57	27	59	55	74	4.43	+ 0.1	9	8,995	n.	42	w.	22	9	13	8	5.0	0.0	0.0
Montgomery	223	100	112	29.85	30.10	+ .07	64.4	− 0.8	87	25	75	40	11	54	31	56	50	64	6.55	+ 2.3	6	5,233	se.	38	sw.	25	15	7	8	4.4	0.0	0.0
Corinth	469	6																														
Meridian	375	85	93	29.67	30.07	+ .05	62.2	− 1.9	85	25	72	36	12	52	38	55	50	71	6.67	+ 1.6	8	4,601	n.	30	se.	13	12	10	8	4.3	0.0	0.0
Vicksburg	247	65	73	29.79	30.07	+ .07	63.2	− 2.0	85	25	73	39	17	54	27	57	54	78	11.49	+ 6.3	11	5,757	se.	34	w.	21	13	6	11	5.0	0.0	0.0
New Orleans	53	76	84	30.00	30.05	+ .05	68.2	+ 0.3	84	14	76	44	18	60	22	62	58	73	4.87	0.0	7	6,209	se.	27	se.	13	12	8	10	4.5	0.0	0.0
West Gulf States.							**63.9**	**− 1.9**										**71**	**4.48**	**+ 0.9**										**4.5**		
Shreveport	249	77	93	29.76	30.03	+ .06	63.1	− 2.7	84	25	73	35	17	53	33	56	51	70	6.24	+ 1.7	12	6,045	se.	34	nw.	16	15	5	10	4.4	0.0	0.0
Bentonville	1,303	11	44	28.61	29.98	+ .02	56.6	− 0.3	81	23	67	26	17	46	33				4.54	+ 0.6	10	5,355	s.	32	s.	20	12	11	7	4.5	T.	0.0
Fort Smith	457	79	94	29.50	29.98	+ .02	60.2	− 1.5	85	23	71	31	17	50	34	53	48	68	5.40	+ 1.5	11	6,266	e.	34	w.	25	15	5	10	4.9	0.0	0.0
Little Rock	357	136	144	29.63	30.01	+ .03	60.4	− 2.3	83	23	70	34	17	51	40	54	49	70	7.40	+ 2.9	13	7,336	s.	48	s.	6	15	6	9	4.5	0.0	0.0
Brownsville	57	4	26				74.4		99	21	84	46	18	64	32				0.52		4		se.								0.0	0.0
Corpus Christi	20	69	77	29.95	29.97	+ .02	70.6	− 0.3	89	13	77	48	17	64	23	64	60	77	0.44	− 1.4	7	11,047	se.	42	s.	24	9	9	12	5.7	0.0	0.0
Dallas	512	109	117	29.44	29.98		62.9		82	23	74	34	17	52	31				3.97		9	8,048	se.	41	nw.	16	13	12	5	4.3	0.0	0.0
Fort Worth	670	106	114	29.24	29.95	+ .01	62.8	− 2.5	83	22	74	35	17	52	32	54	48	65	1.99	− 0.7	6	8,967	s.	42	nw.	16	13	11	6	4.3	0.0	0.0
Galveston	54	106	114	29.96	30.02	+ .05	67.4	− 1.3	78	16	72	43	17	62	24	63	60	78	2.47	− 0.7	10	9,868	se.	52	se.	12	10	10	10	4.8	0.0	0.0
Groesbeck	461	11	56	29.50	29.98		62.9		82	25	73	35	17	52	31				6.74		10	9,024	s.	50	sw.	26	13	6	11	4.5	0.0	0.0
Houston	138	111	121	29.85	30.00		67.0	− 2.6	87	14	76	40	17	58	25				3.38		9	7,864	se.	35	se.	21	16	8	6	3.6	0.0	0.0
Palestine	510	64	72	29.47	30.01	+ .05	62.8	− 3.1	82	23	73	34	17	53	29	56	51	71	6.75	+ 2.7	12	6,439	s.	38	se.	5	14	5	11	5.1	0.0	0.0
Port Arthur	34	58	66	29.97	30.01		66.8		81	14	73	43	17	60	26	62	58	76	3.13		10	8,886	s.	52	se.	21	17	4	9	4.1	0.0	0.0
San Antonio	701	119	132	29.24	29.96	+ .03	67.5	− 1.5	94	25	79	40	11	56	31	57	50	62	2.78	− 0.2	12	6,976	se.	42	nw.	25	13	12	5	4.1	0.0	0.0
Taylor	582	55	63	29.40	30.01	+ .06	64.4	− 3.1	87	25	75	39	17	54	33				6.78	+ 2.8	14	7,653	se.	39	s.	5	12	8	10	4.8	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, April, 1921*—Continued.

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.												Precipitation.			Wind.										
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0-10	In.	In.
Ohio Valley and Tennessee.							**57.4**	**+ 2.8**										**66**	**3.97**	**+ 0.4**										**5.2**		
Chattanooga	762	18	213	29.29	30.10	+ .07	60.4	+ 0.4	83	25	71	35	11	50	34	51	44	61	5.09	+ 0.7	5	6,554	nw.	40	w.	16	11	13	6	4.6	0.0	0.0
Knoxville	996	102	111	29.02	30.08	+ .05	59.4	+ 2.6	87	25	71	32	11	47	37	51	44	61	3.16	− 1.5	8	4,380	ne.	32	s.	14	11	9	10	5.1	0.0	0.0
Memphis	399	76	97	29.66	30.08	+ .08	61.0	− 0.8	85	25	70	35	17	52	37	53	47	61	11.64	+ 6.8	9	6,832	se.	42	sw.	26	14	8	8	4.6	0.0	0.0
Nashville	546	168	191	29.50	30.09	+ .08	59.2	+ 0.1	82	26	70	34	11	49	34	51	44	62	3.50	− 0.9	10	7,924	s.	45	se.	13	11	11	8	4.9	T.	0.0
Lexington	98	193	23	29.00	30.07	+ .05	57.5	+ 3.8	85	24	67	26	11	48	27	.....	.....	.....	3.28	− 0.1	14	10,480	sw.	50	s.	14	11	9	10	4.9	0.1	0.0
Louisville	525	219	255	29.48	30.06	+ .05	59.0	+ 2.8	86	25	69	32	11	49	29	51	46	66	4.58	+ 0.5	11	9,607	s.	58	s.	26	11	8	11	5.1	T.	0.0
Evansville	431	13	175	29.58	30.05	+ .05	58.8	+ 2.4	86	25	69	32	18	49	30	50	44	61	3.42	0.0	11	9,695	sw.	42	sw.	21	8	13	9	5.4	T.	0.0
Indianapolis	822	194	230	29.14	30.03	+ .03	55.8	+ 3.4	81	24	65	28	11	47	29	49	43	68	3.73	+ 0.3	15	9,540	s.	38	w.	9	10	6	14	5.8	0.2	0.0
Royal Center	73	11	55	.....	.....	.....	.....	.....	.....		.....	.....		.....	.....	.....	.....	.....	.....	.....		.....	.....	.....	.....		.....	.....	.....	.....	.....	.....
Terre Haute	575	96	12	29.37	29.99	.....	56.8	.....	84	25	66	30	11	48	30	50	46	73	1.97	.....	12	8,774	s.	39	nw.	25	8	10	12	5.9	T.	0.0
Cincinnati	628	11	51	29.38	30.06	+ .05	56.2	+ 3.9	82	26	67	26	11	46	29	.....	.....	.....	3.19	+ 0.2	13	5,776	sw.	34	s.	22	10	10	10	5.3	T.	0.0
Columbus	824	17	222	29.18	30.05	+ .03	55.0	+ 4.0	82	26	65	26	11	45	30	50	45	72	4.11	+ 1.2	15	8,465	sw.	36	nw.	17	13	7	10	4.9	0.3	0.0
Dayton	899	181	216	29.05	30.00	.....	55.6	+ 3.9	81	26	65	28	11	46	28	50	45	71	3.42	+ 0.5	12	8,160	sw.	48	se	16	12	8	10	4.7	0.2	0.0
Elkins	1,947	59	67	28.02	30.08	+ .05	51.9	+ 3.2	84	25	65	22	11	38	43	46	40	71	2.26	− 1.0	14	4,205	nw.	27	nw.	17	10	6	14	5.9	0.8	0.0
Parkersburg	638	77	84	29.41	30.07	+ .04	57.6	+ 4.6	87	26	70	28	11	46	39	49	42	63	2.50	− 0.4	11	4,244	se.	32	nw.	17	13	6	11	4.8	T.	0.0
Pittsburgh	842	353	410	29.14	30.05	+ .03	56.9	+ 5.9	84	25	67	26	11	47	32	49	43	64	1.66	− 1.2	13	7,668	sw.	39	nw.	8	11	4	15	6.1	0.6	0.0
Lower Lake region.							**52.7**	**+ 7.5**										**71**	**3.00**	**+ 0.6**										**5.7**		
Buffalo	767	247	280	29.18	30.02	+ .01	51.3	+ 9.0	84	26	59	24	10	43	30	45	41	74	3.62	+ 1.2	14	10,201	sw.	56	w.	2	9	7	14	6.5	2.0	0.0
Canton	448	10	61	29.54	30.02	.....	48.5	+ 6.0	81	27	59	21	11	38	38	.....	.....	.....	1.53	− 0.7	11	8,264	sw.	44	w.	2	14	9	7	4.5	2.3	0.0
Oswego	335	76	91	.....	30.02	+ .01	50.2	+ 7.0	77	27	50	26	1	41	38	.....	.....	.....	2.01	− 0.2	10	7,583	s.	34	nw.	16	9	8	13	.....	0.2	0.0
Rochester	523	86	102	29.46	30.04	+ .03	52.5	+ 8.6	80	6	62	24	11	43	34	46	40	68	2.58	+ 0.1	13	6,129	sw.	38	w.	2	10	6	14	6.0	0.5	0.0
Syracuse	597	97	113	29.40	30.01	+ .03	53.0	+ 8.6	83	26	62	24	11	44	38	.....	.....	.....	2.90	+ 0.6	12	7,390	nw.	41	s.	8	7	10	13	6.3	0.4	0.0
Erie	714	130	166	29.24	30.02	.00	53.7	+ 9.0	82	26	62	28	10	45	32	48	44	73	3.58	+ 1.2	15	10,284	s.	42	ne.	17	9	7	14	6.2	0.9	0.0
Cleveland	762	190	201	29.20	30.03	+ .01	53.9	+ 7.9	86	26	62	27	10	46	32	47	42	68	2.58	+ 0.3	12	9,749	s.	46	ne.	17	12	5	13	5.7	1.7	0.0
Sandusky	629	62	103	29.33	30.01	− .01	54.8	+ 7.5	85	26	63	28	11	46	31	.....	.....	.....	2.65	+ 0.1	12	10,130	sw.	42	n.	10	9	9	12	5.7	0.6	0.0
Toledo	628	208	243	29.33	30.01	.00	54.3	+ 7.0	84	26	64	28	10	45	30	48	43	69	5.34	+ 3.1	14	11,706	sw.	47	sw.	27	10	9	11	5.3	7.5	0.0
Fort Wayne	856	113	124	29.09	30.02	.....	54.0	+ 4.7	81	6	63	27	11	45	30	47	43	71	3.14	.....	15	8,040	sw.	38	sw.	27	10	4	16	5.8	1.8	0.0
Detroit	730	218	245	29.22	30.02	.00	53.2	+ 7.7	83	26	62	25	10	44	30	47	43	73	3.18	+ 0.8	13	8,698	sw.	46	sw.	27	11	6	13	5.4	4.6	0.0
Upper Lake region.							**47.4**	**+ 6.6**										**73**	**3.84**	**+ 1.5**										**5.8**		
Alpena	609	13	92	29.33	30.00	− .02	44.8	+ 6.8	81	5	54	19	1	36	43	40	36	77	2.52	+ 0.3	11	9,253	nw.	42	ne.	21	9	9	12	5.9	1.2	0.0
Escanaba	612	54	60	29.29	29.96	− .06	42.6	+ 5.4	67	7	50	24	10	35	29	38	34	77	3.41	+ 1.3	10	8,829	s.	40	s.	27	16	6	8	4.5	T.	0.0
Grand Haven	632	54	89	29.28	29.97	− .04	48.8	+ 4.8	76	6	57	24	1	41	25	44	39	72	4.34	+ 1.9	17	10,294	s.	38	s.	27	9	7	14	5.8	3.2	0.0
Grand Rapids	707	70	87	29.22	29.99	− .03	52.6	+ 6.4	81	6	62	25	16	44	29	46	40	67	4.39	+ 1.9	15	4,751	s.	24	nw.	30	7	6	17	6.7	1.0	0.0
Houghton	684	62	99	29.21	29.95	− .07	42.5	+ 5.6	85	25	52	20	1	33	41	.....	.....	.....	4.26	+ 2.2	9	8,405	e.	45	sw.	25	9	12	9	5.4	0.2	0.0
Lansing	878	11	62	29.01	29.99	.....	51.6	+ 6.0	82	25	62	19	1	41	33	45	41	74	3.80	+ 1.3	16	5,544	sw.	27	sw.	27	8	6	16	6.5	4.2	0.0
Ludington	637	60	66	29.27	29.97	.....	47.2	.....	74	24	55	23	16	39	24	44	39	76	3.38	.....	11	9,587	s.	44	s.	27	10	10	10	5.4	7.6	0.0
Marquette	734	77	111	29.18	29.99	− .03	44.6	+ 7.1	82	25	53	22	1	36	32	39	34	72	4.10	+ 2.1	12	8,458	w.	44	s.	25	9	6	15	6.3	0.5	0.0
Port Huron	638	70	120	29.30	30.00	− .02	50.8	+ 8.6	80	26	60	23	11	42	32	46	43	78	4.06	+ 2.0	10	9,325	s.	35	ne.	16	11	8	11	5.3	6.0	0.0
Saginaw	641	69	77	29.29	29.99	.....	51.7	.....	80	25	61	23	1	42	32	46	41	72	3.67	+ 1.0	12	7,503	sw.	36	sw.	27	8	7	15	6.2	0.5	0.0
Sault Sainte Marie	614	11	52	29.30	30.00	− .03	43.0	+ 7.3	76	25	53	15	10	33	37	39	35	75	2.64	+ 0.6	11	6,966	se.	36	nw.	2	6	12	12	6.3	0.1	0.0
Chicago	823	140	310	29.09	29.98	− .02	54.2	+ 8.3	81	24	62	28	10	46	29	47	41	66	4.47	+ 1.6	14	11,007	s.	56	ne.	16	9	11	10	5.4	0.4	0.0
Green Bay	617	109	144	29.27	29.93	− .08	49.9	+ 9.2	78	25	59	24	10	41	37	43	39	71	4.13	+ 1.7	9	10,890	s.	48	sw.	27	6	12	12	5.9	0.0	0.0
Milwaukee	681	125	139	29.21	29.95	− .04	49.9	+ 8.1	79	24	59	26	16	41	34	44	41	79	5.90	+ 3.2	13	8,911	sw.	50	ne.	16	8	9	13	6.0	15.0	0.0
Duluth	1,133	11	47	28.71	29.95	− .06	40.8	+ 2.4	72	25	49	21	16	33	36	35	30	70	2.10	0.0	9	11,752	ne.	54	nw.	27	12	9	9	4.9	5.0	0.0
North Dakota.							**41.8**	**+ 1.1**										**66**	**2.00**	**+ 0.1**										**6.1**		
Moorhead	940	50	58	28.89	29.92	− .07	44.1	+ 2.7	78	3	55	18	16	33	40	38	32	69	1.79	− 0.5	12	7,037	n.	36	sw.	7	11	7	12	5.1	0.4	0.0
Bismarck	1,674	8	57	28.14	29.95	− .02	43.4	+ 0.8	82	3	56	15	8	30	47	36	27	62	2.40	+ 0.5	9	7,535	nw.	35	w.	7	11	11	8	4.7	1.0	0.0
Devils Lake	1,482	11	44	28.33	29.93	− .06	39.2	+ 1.0	71	18	50	15	8	29	39	34	29	72	2.17	+ 0.1	9	9,316	ne.	36	ne.	20	13	7	10	4.7	1.9	0.0
Ellendale	1,457	10	56	28.34	29.91	.....	43.8	.....	81	4	57	17	16	31	46	.....	.....	.....	1.66	.....	11	12,042	nw.	43	sw.	7	8	12	10	5.3	0.9	0.0
Grand Forks	835	12	89	.....	.....	.....	42.2	.....	73	3	53	12	16	31	45	38	.....	.....	1.72	.....	11	.....	n.	36	w.	7	14	8	8	.....	1.2	0.0
Williston	1,878	41	48	27.92	29.93	− .03	40.4	− 0.1	74	2	52	14	8	29	40	34	26	63	1.66	+ 0.4	7	6,997	e.	42	e.	29	11	11	8	4.5	6.5	T.
Upper Mississippi Valley.							**53.9**	**+ 3.4**										**68**	**4.29**	**+ 1.3**										**5.9**		
Minneapolis	918	102	208	28.90	29.88	.....	50.6	.....	81	4	60	23	16	41	31	.....	.....	.....	2.04	− 0.4	10	9,816	s.	42	n.	16	6	13	11	6.2	0.1	0.0
St. Paul	837	236	261	29.00	29.91	− .08	50.4	+ 4.7	79	24	60	25	16	40	32	.....	.....	.....	2.46	− 0.1	11	10,594	se.	44	se.	24	8	14	8	5.5	T.	0.0
La Crosse	714	11	48	29.14	29.92	− .06	52.6	+ 5.3	82	24	63	26	10	42	37	.....	.....	.....	3.37	+ 1.1	13	4,998	s.	26	nw.	27	5	11	14	6.6	0.4	0.0
Madison	974	70	78	28.90	29.95	− .04	50.6	+ 6.1	80	24	60	24	10	42	26	45	40	72	5.16	+ 2.8	15	8,755	s.	49	ne.	16	5	9	16	7.0	13.0	0.0
Wausau	1,247	4	.....	28.58	29.92	.....	47.8	.....	80	25	58	19	10	37	36	.....	.....	.....	4.22	.....	12	.....	e.	.....	.....	.....	8	11	11	5.8	2.8	0.0
Charles City	1,015	10	49	28.85	29.93	− .05	50.8	+ 4.5	80	24	62	26	17	40	37	45	40	73	3.59	+ 0.8	10	6,482	nw.	30	sw.	1	6	12	12	6.2	0.5	0.0
Davenport	606	71	79	29.30	29.96	− .02	53.8	+ 3.6	81	24	63	25	16	44	29	47	41	68	4.77	+ 1.9	16	7,053	s.	39	ne.	15	10	7	13	5.4	2.7	0.0
Des Moines	861	84	97	29.00	29.91	− .06	52.8	+ 2.2	84	24	63	24	16	43	39	46	39	65	3.72	+ 0.7	11	7,109	s.	40	sw.	24	10	8	12	5.8	8.9	0.0
Dubuque	698	81	96	29.21	29.96	− .02	52.2	+ 3.3	81	24	62	25	16	43	33	45	40	68	4.70	+ 1.8	15	5,868	s.	32	nw.	27	8	10	12	6.1	10.1	0.0
Keokuk	614	61	78	29.29	29.97	− .01	54.7	+ 2.7	80	25	64	28	16	45	30	47	41	64	3.91	+ 0.6	13	7,194	sw.	49	w.	25	5	12	13	6.4	0.9	0.0
Cairo	356	87	93	29.64	30.03	− .04	59.0	+ 0.7	83	25	68	34	17	50	39	51	45	65	3.67	+ 0.1	12	6,849	s.	42	e.	16	9	8	13	5.7	T.	0.0
Peoria	609	11	45	29.31	29.98	− .01	54.3	+ 3.4	82	25	65	28	17	44	34	48	43	72	6.36	+ 3.1	14	6,617	s.	36	ne.	16	10	9	11	5.0	0.1	0.0
Springfield, Ill	644	10	91	29.29	29.97	− .01	55.6	+ 3.6	83	25	66	29	17	46	30	49	44	70	4.75	+ 1.4	13	7,579	s.	39	ne.	16	8	10	12	5.8	0.8	0.0
Hannibal	534	74	109	29.40	29.97	− .01	55.8	+ 2.2	83	25	66	29	17	46	34	.....	.....	.....	4.58	+ 1.3	13	8,210	sw.	38	ne.	16	8	9	13	5.9	T.	0.0
St. Louis	567	265	303	29.38	29.98	.00	58.1	+ 2.0	82	25	68	30	17	49	30	49	42	62	7.01	+ 3.5	13	11,914	s.	48	s.	24	12	10	8	4.6	T.	0.0
Missouri Valley.							**52.7**	**+ 2.0**										**66**	**2.49**	**− 0.4**										**5.2**		
Columbia, Mo	781	11	84	29.14	29.98	.00	55.8	+ 1.5	86	23	66	28	16	45	42	.....	.....	.....	5.51	+ 1.8	15	7,084	s.	30	ne.	16	8	12	10	5.7	T.	0.0
Kansas City	963	161	181	28.91	29.95	− .01	55.9	+ 1.6	83	23	65	28	16	47	29	48	41	62	2.71	− 0.6	11	9,826	s.	45	n.	16	13	9	8	4.7	0.6	0.0
St. Joseph	967	11	49	28.88	29.92	.....	55.4	.....	86	23	66	24	17	45	36	47	40	73	3.21	.....	10	7,975	s.	33	sw.	20	12	9	9	4.8	7.0	0.0
Springfield, Mo	1,324	98	104	28.58	29.99	+ .02	55.6	− 0.1	82	23	65	27	17	46	29	48	43	68	4.79	+ 0.9	11	9,500	s.	39	s.	24	15	4	11	4.7	T.	0.0
Iola	984	11	50	28.90	29.95	.00	56.2	+ 2.0	83	23	67	27	17	45	37	.....	.....	.....	2.86	+ 0.1	12	7,046	s.	32	se.	23	12	11	7	4.9	T.	0.0
Topeka	987	92	107	.....	.....	.....	55.3	− 0.4	85	23	67	26	16	44	37	.....	.....	.....	2.35	− 0.4	11	10,049	s.	44	n.	16	11	7	12	4.9	1.0	0.0
Drexel	1,299	10	53	28.50	29.90	.....	51.6	.....	87	24	63	21	10	40	42	45	39	69	3.33	.....	13	10,595	s.	47	sw.	3	9	11	10	5.6	0.8	0.0
Lincoln	1,189	11	84	28.62	29.88	− .06	53.9	+ 3.2	89	23	66	24	10	42	40	46	39	65	3.04	+ 0.3	11	9,161	s.	50	ne.	15	9	9	12	5.9	3.0	0.0
Omaha	1,105	115	122	28.73	29.91	− .04	54.2	+ 3.7	87	3	65	25	9	44	40	47	41	66	2.13	− 0.9	13	6,875	s.	37	n.	16	10	9	11	5.5	0.5	0.0
Valentine	2,598	47	54	27.18	29.91	− .03	45.9	+ 0.5	83	23	59	11	7	32	45	38	29	61	1.17	− 1.2	10	8,650	nw.	38	nw.	8	8	13	9	5.4	6.5	0.0
Sioux City	1,135	94	164	28.69	29.91	− .04	52.0	+ 3.5	85	3	63	23	10	41	39	44	36	60	0.99	− 1.8	8	10,969	s.	54	nw.	24	10	8	12	5.8	T.	0.0
Huron	1,306	59	74	28.51	29.91	− .05	48.1	+ 3.5	81	4	61	20	10	35	43	42	37	72	1.88	− 0.8	9	8,077	nw.	48	sw.	4	14	7	9	4.4	0.3	0.0
Pierre	1,572	70	75	28.23	29.90	− .05	48.1	+ 1.6	86	4	61	18	7	35	47	41	35	69	1.33	− 0.6	10	7,851	nw.	44	se.	4	16	3	11	4.7	4.0	0.0
Yankton	1,233	49	57	28.57	29.89	− .06	51.2	+ 2.8	86	23	63	21	10	40	44	.....	.....	.....	1.15	− 1.6	10	7,447	nw.	36	s.	4	9	9	12	6.1	T.	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, April, 1921*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature of the air: Mean max. + mean min. ÷ 2.	Temperature of the air: Departure from normal.	Temperature of the air: Maximum.	Temperature of the air: Date.	Temperature of the air: Mean maximum.	Temperature of the air: Minimum.	Temperature of the air: Date.	Temperature of the air: Mean minimum.	Temperature of the air: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 inch or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0-10	In.	In.
Northern Slope.							41.7	− 0.9										58	1.41	− 0.2										5.3		
Billings	3,140	5	...	...	...	...	45.6	...	81	2	62	17	10	29	57	...	...	...	0.83	...	7	...	...	...	...	...	3	17	10	...	4.5	0.0
Havre	2,505	11	44	27.29	29.95	− .02	43.1	+ 0.4	74	2	55	14	9	31	42	36	30	68	0.92	− 0.1	11	6,169	e.	34	sw.	29	9	11	10	5.2	6.0	0.0
Helena	4,110	87	112	25.72	29.95	− .02	41.8	− 0.2	73	2	51	15	9	32	38	34	25	55	1.07	− 0.1	11	6,800	sw.	37	sw.	30	4	12	14	6.8	5.5	0.0
Kalispell	2,973	48	56	...	29.94	− .02	42.1	− 0.4	66	16	51	25	8	33	33	...	...	...	1.17	+ 0.1	9	4,570	nw.	38	sw.	29	6	15	9	...	3.5	0.0
Miles City	2,371	26	48	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Rapid City	3,259	50	58	26.51	29.95	.00	45.0	+ 1.5	81	2	57	15	16	33	50	36	24	48	0.36	− 1.9	6	7,988	n.	36	n.	4	10	12	8	5.4	2.1	0.0
Cheyenne	6,088	84	101	23.89	29.91	.00	38.8	− 2.8	69	23	50	11	9	28	40	31	22	57	2.00	+ 0.2	9	10,963	w.	50	ne.	15	7	14	9	5.3	9.9	0.0
Lander	5,372	60	68	24.55	29.95	+ .01	39.4	− 2.8	70	1	52	6	7	26	39	32	24	60	2.73	+ 0.3	6	4,287	w.	58	w.	29	8	15	7	5.1	21.0	0.0
Sheridan	3,790	10	47	26.02	29.94	...	43.0	...	79	2	56	13	9	30	54	34	24	56	0.62	...	11	6,273	nw.	58	nw.	29	15	7	8	3.9	0.6	0.0
Yellowstone Park	6,200	11	48	23.77	29.95	− .01	34.6	− 2.4	59	3	46	5	9	24	49	28	21	61	1.70	+ 0.3	11	6,234	sw.	36	s.	29	5	12	13	6.2	11.1	0.0
North Platte	2,821	11	51	26.99	29.93	+ .01	48.6	− 0.4	85	23	63	18	10	34	48	39	31	60	1.30	− 0.8	7	6,067	w.	42	ne.	15	13	8	9	4.8	1.4	0.0
Middle Slope.							52.8	− 1.0										59	2.52	+ 0.3										4.6		
Denver	5,292	106	113	24.62	29.90	.00	45.2	− 2.5	77	23	56	20	17	35	37	36	26	54	2.31	+ 0.1	8	6,534	s.	48	n.	15	10	12	8	5.1	16.2	0.0
Pueblo	4,685	80	86	25.18	29.86	− .02	48.0	− 2.5	82	23	62	19	10	34	47	37	25	50	0.79	− 0.6	5	4,759	nw.	24	ne.	14	7	18	5	5.4	3.6	0.0
Concordia	1,392	50	58	28.45	29.93	.00	54.6	+ 1.0	88	23	66	27	10	43	40	46	39	63	2.79	+ 0.4	12	8,705	s.	46	se.	5	10	12	8	5.1	0.1	0.0
Dodge City	2,509	11	51	27.32	29.92	+ .02	53.8	− 0.6	90	23	67	23	10	41	40	43	34	58	2.73	+ 0.9	7	9,064	nw.	39	se.	4	16	9	5	3.5	T.	0.0
Wichita	1,358	139	158	28.48	29.90	− .03	56.2	− 0.4	83	23	66	30	10	46	32	48	42	65	4.09	+ 1.4	10	11,549	s.	46	sw.	20	12	14	4	4.2	T.	0.0
Altus	1,410	5	...	...	...	...	60.4	...	95	23	74	28	17	47	45	...	...	...	2.27	...	5	...	se.	...	...	...	19	3	8	...	0.0	0.0
Broken Arrow	765	11	52	29.13	29.96	...	58.0	...	82	23	68	29	17	48	31	...	...	...	8.87	...	6	11,426	s.	54	sw.	20	12	8	10	4.8	0.0	0.0
Muskogee	652	4	...	...	...	...	59.9	...	84	23	72	29	17	48	38	...	...	...	4.99	...	8	...	e.	...	...	...	14	5	11	...	0.0	0.0
Oklahoma City	1,214	10	47	28.67	29.95	+ .03	58.8	− 0.8	85	23	70	30	17	48	34	50	44	65	2.39	− 0.4	7	11,734	s.	46	s.	24	15	10	5	3.8	0.0	0.0
Southern Slope.							61.0	− 1.4										43	0.50	− 1.1										3.3		
Abilene	1,738	10	52	28.12	29.92	+ .02	63.0	− 1.4	94	24	76	30	17	49	44	49	37	47	0.30	− 2.0	3	9,609	s.	36	sw.	15	17	8	5	3.5	0.0	0.0
Amarillo	3,676	10	49	26.17	29.88	+ .01	55.0	+ 0.4	89	19	70	23	17	40	46	43	33	53	0.39	− 1.3	3	9,256	sw.	40	n.	16	21	9	0	3.2	T.	0.0
Del Rio	944	64	71	28.98	29.96	+ .07	68.6	− 1.4	98	24	81	41	11	56	38	...	...	...	1.31	− 0.6	4	7,964	se.	50	ne.	30	19	4	7	3.5	0.0	0.0
Roswell	3,566	75	85	26.27	29.85	.00	57.6	− 3.0	87	23	73	32	1	42	46	41	19	28	0.01	− 0.5	1	8,064	s.	52	sw.	24	17	11	2	2.9	0.0	0.0
Southern Plateau.							55.5	− 2.3										32	0.12	− 0.2										2.3		
El Paso	3,762	110	133	26.12	29.84	+ .01	61.0	− 2.8	88	29	74	34	6	48	40	43	19	24	0.01	− 0.2	1	11,102	w.	65	w.	24	24	5	1	1.9	T.	0.0
Santa Fe	7,013	57	66	23.14	29.86	+ .02	43.4	− 4.2	72	23	56	18	25	31	34	32	19	46	0.55	− 0.3	7	7,663	sw.	42	sw.	14	14	10	6	4.2	0.2	0.0
Flagstaff	6,908	10	59	23.26	29.84	− .03	40.4	− 1.8	69	22	56	13	7	25	43	30	...	...	1.01	...	6	6,967	w.	28	s.	4	20	7	3	...	5.7	0.0
Phoenix	1,108	76	81	28.71	29.85	− .02	66.1	− 0.5	96	29	82	37	5	50	44	48	27	29	0.02	− 0.4	1	4,905	w.	29	w.	24	24	5	1	1.8	0.0	0.0
Yuma	141	9	54	29.74	29.89	.00	67.8	− 2.3	101	29	84	38	5	51	43	51	33	35	0.00	− 0.1	0	4,826	w.	41	nw.	11	25	5	0	1.2	0.0	...
Independence	3,957	9	41	25.91	29.94	+ .04	54.4	− 2.3	85	29	69	27	6	39	41	39	20	28	T.	− 0.1	0	6,220	nw.	50	nw.	13	19	10	1	2.6	0.0	0.0
Middle Plateau.							46.1	− 2.1										50	0.88	− 0.3										5.2		
Reno	4,532	74	81	25.44	29.98	+ .01	46.4	− 0.9	76	28	60	20	7	33	44	36	25	47	0.01	− 0.6	1	6,705	w.	42	w.	22	12	13	5	4.3	T.	0.0
Tonopah	6,090	12	20	24.01	29.93	...	45.3	...	76	22	57	16	4	34	41	34	21	44	0.07	− 1.6	3	9,164	nw.	45	nw.	23	13	15	2	4.0	1.5	0.0
Winnemucca	4,344	18	56	25.58	29.98	+ .02	45.1	− 2.0	74	1	59	15	25	31	43	36	25	52	0.06	− 0.8	3	6,419	sw.	38	nw.	3	11	4	15	5.8	0.2	0.0
Modena	5,479	10	43	24.52	29.87	− .01	43.0	− 0.3	75	30	58	14	24	28	41	33	20	48	1.33	+ 0.5	7	8,557	w.	61	s.	3	13	12	5	3.9	5.6	0.0
Salt Lake City	4,360	163	203	25.54	29.91	− .01	47.0	− 3.1	71	2	56	25	7	38	27	38	30	57	2.65	+ 0.4	11	6,012	nw.	40	s.	3	5	19	16	6.7	8.6	0.0
Grand Junction	4,602	60	68	25.27	29.84	− .04	49.0	− 4.0	76	30	61	23	8	37	35	39	27	50	1.16	+ 0.4	9	5,155	se.	37	sw.	11	4	13	13	6.3	2.4	0.0
Northern Plateau.							45.8	− 3.1										61	1.40	0.0										6.5		
Baker	3,471	48	53	26.43	30.04	+ .04	41.5	− 2.0	70	1	52	22	7	31	37	36	30	68	0.66	− 0.3	11	5,714	se.	28	w.	22	6	14	10	5.4	2.0	0.0
Boise	2,739	78	86	27.14	30.01	+ .03	47.0	− 3.1	76	2	58	26	25	36	36	40	33	62	0.93	− 0.2	12	5,263	nw.	33	nw.	5	8	7	15	6.0	2.3	0.0
Lewiston	757	40	48	29.22	30.04	+ .05	49.6	− 3.3	73	1	60	28	8	39	40	...	...	...	1.61	+ 0.5	14	3,194	e.	32	nw.	29	2	10	18	7.7	0.0	0.0
Pocatello	4,477	60	68	25.39	29.94	.00	41.1	− 5.7	71	2	51	11	7	31	40	35	27	61	3.23	+ 1.2	15	6,978	sw.	40	sw.	3	4	7	19	6.9	22.5	0.0
Spokane	1,929	101	110	27.94	30.01	+ .02	45.6	− 2.1	72	10	55	27	8	36	30	39	31	60	1.16	− 0.1	10	5,533	sw.	33	sw.	29	2	16	12	7.0	T.	0.0
Walla Walla	991	57	65	28.96	30.04	+ .03	50.2	− 2.6	72	9	60	32	7	40	35	42	32	53	0.81	− 0.9	11	4,584	s.	29	w.	29	7	12	11	6.2	2.3	0.0
North Pacific Coast region.							48.1	− 0.9										75	3.06	− 0.4										6.9		
North Head	211	11	56	29.87	30.11	+ .06	46.6	− 0.9	65	8	51	34	3	42	20	44	41	83	4.16	+ 0.9	19	11,401	s.	66	s.	12	5	12	13	6.4	T.	0.0
Port Angeles	29	8	53	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Seattle	125	215	250	29.96	30.09	+ .06	47.5	− 1.9	74	9	54	32	3	40	28	43	37	72	1.76	− 0.9	15	7,107	s.	48	sw.	28	4	8	18	7.4	0.5	0.0
Tacoma	213	113	120	29.86	30.10	+ .07	47.2	− 1.7	74	9	56	30	4	39	29	44	40	78	2.20	− 0.6	16	5,238	sw.	28	sw.	29	1	14	15	7.2	T.	0.0
Tatoosh Island	86	7	57	29.96	30.06	+ .06	45.9	− 0.2	65	9	50	36	3	42	18	43	41	84	6.58	+ 0.3	19	10,777	w.	52	s.	28	6	11	13	6.3	0.0	0.0
Yakima	1,071	4	...	...	...	...	49.8	...	76	11	63	26	24	36	36	...	...	...	0.35	...	3	...	...	...	...	...	18	13	9	...	T.	0.0
Medford	1,425	4	...	...	...	...	50.4	...	78	28	63	24	4	38	42	43	37	68	0.75	...	12	...	nw.	...	...	...	4	6	20	...	T.	0.0
Portland, Oreg.	153	68	106	29.95	30.11	+ .05	50.8	− 0.4	73	9	59	32	4	43	27	45	39	70	2.26	− 0.8	15	4,785	sw.	26	nw.	21	2	7	21	8.0	T.	0.0
Roseburg	510	9	57	29.58	30.14	+ .07	50.8	− 0.1	74	8	62	29	4	40	34	45	39	71	1.38	− 0.1	16	2,434	nw.	19	sw.	22	4	20	6	6.1	T.	0.0
Middle Pacific coast region.							53.2	− 0.6										70	0.73	− 1.6										3.8		
Eureka	62	73	89	30.11	30.18	+ .07	48.4	− 1.1	59	18	54	36	3	43	17	46	44	88	1.67	− 2.3	11	6,302	n.	41	nw.	3	9	6	15	6.1	0.0	0.0
Mount Tamalpais	2,375	11	18	27.60	30.08	+ .03	49.6	+ 0.1	79	28	56	30	4	43	23	...	...	...	0.96	− 0.5	6	16,555	nw.	96	nw.	22	21	6	3	3.0	0.0	0.0
Point Reyes Light	490	7	18	29.53	30.05	...	49.3	− 1.3	65	27	54	39	14	45	19	...	...	...	0.45	...	6	18,776	nw.	100	nw.	3	11	12	7	4.6	0.0	0.0
Red Bluff	332	50	56	29.68	30.04	+ .01	58.1	− 1.0	91	28	70	36	14	47	37	49	39	55	0.43	− 1.4	4	5,070	nw.	30	nw.	22	22	7	1	2.7	0.0	0.0
Sacramento	69	106	117	29.97	30.04	+ .03	57.6	− 0.4	88	28	69	36	14	46	40	51	46	67	0.39	− 1.6	2	6,729	nw.	35	nw.	4	19	10	1	2.8	0.0	0.0
San Francisco	155	208	243	29.91	30.08	+ .07	54.9	+ 1.2	86	27	62	43	4	48	28	49	44	71	0.54	− 1.3	4	7,767	w.	40	nw.	23	13	12	5	4.1	0.0	0.0
San Jose	141	12	110	29.93	30.08	...	54.6	− 2.1	90	27	67	34	15	42	45	...	...	...	0.40	− 1.0	5	5,602	nw.	35	nw.	4	16	10	4	3.0	0.0	0.0
South Pacific coast region.							57.7	− 0.8										64	0.26	− 0.8										2.8		
Fresno	327	89	98	29.66	30.02	+ .03	59.2	− 2.0	90	28	73	36	4	46	36	48	39	53	0.15	− 0.6	2	6,293	nw.	35	nw.	24	21	6	3	2.2	0.0	0.0
Los Angeles	338	159	191	29.64	30.01	+ .02	59.0	− 0.4	95	28	68	42	5	50	32	50	43	63	0.28	− 0.8	2	4,895	sw.	28	nw.	24	18	8	4	3.1	0.0	0.0
San Diego	87	62	70	29.91	30.01	+ .02	57.4	− 0.8	88	28	64	44	5	50	30	51	45	70	0.04	− 0.7	1	6,001	nw.	38	w.	13	18	10	2	2.8	0.0	0.0
San Luis Obispo	201	32	40	29.85	30.07	+ .02	55.1	− 0.1	95	28	67	32	14	43	37	47	41	68	0.57	− 0.9	3	3,680	nw.	27	w.	23	20	8	2	2.9	0.0	0.0
West Indies.																																
San Juan, P. R.	82	8	54	29.94	30.03	...	74.6	...	82	13	80	66	10	69	16	...	...	...	2.48	− 1.4	13	10,246	e.	42	e.	8	7	16	7	5.5	0.0	0.0
Panama Canal.																																
Balboa Heights	118	7	97	29.74	29.86	.00	81.1	− 0.4	93	29	89	70	20	73	21	73	71	78	1.19	− 1.8	5	6,587	nw.	26	nw.	20	4	24	2	5.7	0.0	0.0
Colon	36	7	97	29.84	29.87	.00	81.8	+ 1.0	88	9	86	74	12	77	12	75	73	78	7.43	+ 3.1	16	10,809	n.	28	n.	19	1	20	9	6.5	0.0	0.0
Alaska.																																
Juneau	80	11	49	29.82	29.90	...	41.0	...	58	30	48	29	16	34	24	37	33	77	4.03	...	21	3,239	se.	22	e.	11	1	6	23	8.2	1.9	0.0

TABLE 2.—*Data furnished by the Canadian Meteorological Service, April, 1921.*

Stations.	Altitude above mean sea level, Jan. 1, 1919.	Pressure.			Temperature of the air.						Precipitation.		
		Station reduced to mean of 24 hours.	Sea level reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Feet.	*Inches.*	*Inches.*	*Inches.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, N. F.	125	29.88	30.02	+.13	35.4	+0.9	43.1	27.8	66	10	2.26	−1.90	2.0
Sydney, C. B. I.	48	30.09	30.14	+.25	38.6	+3.6	47.3	29.9	71	18	2.30	−1.55	7.0
Halifax, N. S.	88	29.99	30.10	+.04	41.4	+3.6	48.7	34.1	72	17	3.48	−0.70	2.6
Yarmouth, N. S.	65	29.98	30.05	+.39	44.3	+5.4	51.7	37.0	73	26	2.70	−0.69	0.0
Charlottetown, P. E. I.	38	30.06	30.10	+.20	39.2	+4.0	46.4	32.1	74	17	3.04	+0.39	9.5
Chatham, N. B.	28	30.10	30.13	+.23	41.3	+5.8	51.6	31.0	81	8	3.02	+0.39	12.4
Father Point, Que.	20	30.09	30.11	+.18	35.0	+1.8	43.3	26.7	66	8	1.48	−0.10	1.9
Quebec, Que.	296	29.77	30.10	+.11	39.9	+4.8	48.1	31.7	80	20	2.41	+0.32	3.7
Montreal, Que.	187	29.83	30.04	+.04	46.6	+6.9	56.1	37.1	75	23	1.88	−0.36	2.5
Stonecliffe, Ont.	489	29.38	30.00	−.02	41.4	+3.5	59.2	23.6	82	10	2.24	+0.68	0.7
Ottawa, Ont.	236	29.76	30.03	+.01	47.1	+7.1	58.4	35.8	80	18	2.95	+1.45	3.4
Kingston, Ont.	285	29.70	30.01	+.01	48.0	+8.0	56.8	39.3	74	23	1.80	+0.01	0.0
Toronto, Ont.	379	29.60	30.01	+.01	49.3	+8.5	58.3	40.3	75	26	4.89	+2.52	3.6
Cochrane, Ont.	930												
White River, Ont.	1,244	28.63	29.96	−.08	37.1	+4.1	50.5	23.8	75	−9	1.99	+0.74	2.4
Port Stanley, Ont.	592												
Southampton, Ont.	656	29.27			48.5	+9.8	58.3	38.8	82	19	2.52	+0.72	1.7
Parry Sound, Ont.	688	29.30	29.97	−.05	46.9	+9.3	58.9	35.0	83	14	3.41	+1.50	0.5
Port Arthur, Ont.	644	29.25	29.96	−.07	39.5	+6.0	48.8	30.2	66	14	2.44	+0.72	0.0
Winnepeg, Man.	760	29.12	29.96	−.06	38.2	+2.3	47.5	28.8	70	16	1.86	+0.81	1.4
Minnedosa, Man.	1,690	28.13	29.98	−.03	35.2	−0.8	44.5	25.9	67	5	1.29	+0.23	10.3
Le Pas, Man.	860												
Qu'Appelle, Sask.	2,115	27.64	29.91	−.08	36.2	−1.2	46.1	26.3	69	7	2.88	+1.83	20.3
Medicine Hat, Alb.	2,144												
Moose Jaw, Sask.	1,759												
Swift Current, Sask.	2,392	27.36	30.02	+.06	37.9	−3.4	49.2	26.7	69	10	0.67	−0.26	2.2
Calgary, Alb.	3,428												
Banff, Alb.	4,521												
Edmonton, Alb.	2,150	27.61	29.91	+.02	41.2	+1.3	53.3	29.2	64	19	0.33	−0.55	2.5
Prince Albert, Sask.	1,450	28.42	30.02	+.04	33.9	−2.2	44.7	23.1	50	4	3.13	+2.30	26.5
Battleford, Sask.	1,592	28.21	29.98	+.01	35.4	−1.8	45.0	25.9	60	5	3.35	+2.88	16.6
Kamloops, B. C.	1,262												
Victoria, B. C.	230	29.81	30.07	+.06	46.5	−0.3	53.1	40.0	66	32	1.13	−1.24	0.0
Barkerville, B. C.	4,180												
Triangle Island, B. C.	680												
Prince Rupert, B. C.	170												
Hamilton, Ber.	151												

SEISMOLOGICAL REPORTS FOR APRIL, 1921.

W. J. HUMPHREYS, Professor in Charge.

[Weather Bureau, Washington, D. C., June 3, 1921.]

TABLE 1.—*Noninstrumental earthquake reports, April, 1921.*

Day.	Approximate time, Greenwich civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
1921.		ARIZONA.								
	H. m.		° ′	° ′			Sec.			
Apr. 6	21 07	St. Michaels	35 40	109 05	5	1	5 ca	Rumbling	Felt by many	F. Brurning.
	21 08	Pinto	35 05	109 30	5	2	15 ca	None	Felt by several	C. F. Henning.
	21 20	Holbrook	34 55	110 05	5	1	10	.....do	.....do	J. M. Lee.
		CALIFORNIA.								
21	15 30	Los Angeles	34 03	118 15	2	1	1	Faint	Felt by many	A. F. Young.
24	15 06	Eureka	40 48	124 10	4	1	3-4	None	.....do	J. M. Jones.
		SOUTH CAROLINA.								
19	23 45	Summerville	33 05	80 15				Rumbling	.....do	E. G. Robertson.
23	23 48	.....do	33 05	80 15		1	10-15	.....do	Felt by several	E. P. Lawton.

TABLE 2.—*Instrumental seismological reports, April, 1921.*

[Time used: Mean Greenwich, midnight to midnight. Nomenclature: International.]

[For description of stations and instruments, see the REVIEW for January, 1921, p. 47.]

CALIFORNIA. *Theosophical University, Point Loma.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude.		Distance.	Remarks.
					A_E	A_N		
1921.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 3					100	100		Tremors.
6					100	100		
12					150	150		
21					100	100		

COLORADO. *Sacred Heart College, Denver.*

Date.	Character.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 30		P_N	6 43? ..					First prelim. not discernible on EW.; doubtful on NS.
		S	6 47 ..					
		L	6 50 30	0.2	*20,000	*22,000		
		M	6 50 30	0.2	*20,000	*22,000		
		C	6 56 ..					
		F_N	7 13 ..					
		F_E	7 15 ..					

* Trace amplitude.

DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.*

Date.	Character.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 1		eL	5 15 ..					
		L	5 21 ..	24				
		F	5 50 ca.					
1		eL	13 04 ..					
		F	13 20 ca.					
5		e	0 35 30					
		F	0 40 ..					
10		e	13 57 ..					
		eL	14 01 ..					
		F	14 45 ..					
12		P?	7 39 54					
		L	7 50 ..	12				
		F	8 20 ..					

HAWAII. *U. S. C. & G. S. Magnetic Observatory, Honolulu.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude.		Distance.	Remarks.
					A_E	A_N		
1921.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 1		e_E	12 16 23					The first phase resembles S, but no evidence of P could be found among the preceding microseisms. Microseisms are continuously present with amplitudes ranging from 0.5 mm. to 2.0 mm. and predominant periods of about 4ˢ and 8ˢ.
		e_N	12 16 15					
		L_E	12 20 15					
		L_N	12 20 13					
		M_E	12 25 24	20	*3,000			
		M_N	12 24 40	13		*4,200		
		C_N	12 28 ..					
		F	12 36 ..					
2		eE	10 06 28					
		eL_E	10 09 32	30				
		M_E	10 23 26	17	*2,200			
		F_E	10 31 ..					
3		L_E	2 54 47	11				No preliminary tremors apparent.
		L_N	2 54 55	12				
		M_E	2 59 04	7	*3,500			
		M_N	2 58 28	8		*4,000		
		C_E	3 01 ..	6				
		C_N	2 59 ..	6				
		F_E	3 07 ..	6				
		F_N	3 08 ..					
10		e_E	13 53 29					The first phases seem more like S than P.
		e_N	13 53 32					
		L_E	13 56 44	10				
		L_N	13 57 14	10				
		M_{1E}	13 59 05	9	*12,000			
		M_{1N}	13 59 00	9		*6,000		
		M_{2E}	14 00 45	9	*11,700			
		M_{2N}	14 00 47	9		*9,800		
		C_E	14 07 ..	8				
		C_N	14 05 ..	8				
		F_E	14 50 ..	7				
		F_N	14 55 ..	7				
12		L_E	7 45 36	10				
		eL_N	7 46 00	10				
		M_E	7 52 07	7	*4,100			
		M_N	7 51 36	7		*2,000		
		C_E	7 55 00	6				
		F_E	8 01 ..					
		F_N	7 59 ..					
22		L_E	6 46 42					
		eL_N	6 51 35					
		M_E	6 49 34	13	*2,500	*1,000		
		F_E	6 57 ..					
		F_N	7 12 ..					
25		L_E	17 52 00					
		L_N	17 52 20					
		M_E	17 55 18	12	*3,000			
		M_N	17 58 09	14		*2,500		
		F_E	18 23 ..					
		F_N	18 17 ..					

* Trace amplitude.

TABLE 2.—*Instrumental seismological reports, April, 1921*—Continued.

ILLINOIS. *U. S. Weather Bureau, Chicago.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km*	
Apr. 1	....	iP.....	4 29 30	......	....	....	9,900?	
		S?.....	4 40 08	......	....	....	......	
		eL....	5 00 00	......	....	....	......	
		L.....	5 18 ..	30	....	....	......	
		L.....	5 37 ..	15	....	....	......	
		F.....	7 *ca.*	......	....	....	......	
1	....	P.....	12 19 18	......	....	....	......	
		S?.....	12 29 ..	......	....	....	......	
		eL....	12 49 ..	......	....	....	......	
		L.....	12 55 ..	20	....	....	......	
		F.....	14 30 *ca.*	......	....	....	......	
2	....	P?....	10 05 05	......	....	....	......	
		S?....	10 10 54	......	....	....	......	
		eL....	10 25 ..	......	....	....	......	
		L.....	10 30 ..	30	....	....	......	
		F.....	12 *ca.*	......	....	....	......	
5	....	e......	0 30 00	......	....	....	......	
		F.....	0 45 *ca.*	......	....	....	......	
10	....	P.....	13 46 55	......	....	....	4,400	
		S.....	13 53 05	......	....	....	......	Rapid vibrations of considerable amplitude; heavy micros.
		L?....	13 58 ..	......	....	....	......	
		F.....	15 20 *ca.*	......	....	....	......	
12	....	P?....	7 40 35	......	....	....	2,600?	
		S?....	7 44 48	......	....	....	......	
		L.....	7 46 30	......	....	....	......	
		F.....	9 *ca.*	......	....	....	......	
20	....	e......	18 53 ..	......	....	....	......	
		L.....	19 04 30	25	....	....	......	
		F.....	20 *postea.*	......	....	....	......	Lost in heavy micros.
22	....	P?....	7 12 ..	......	....	....	......	
		eL....	7 21 ..	20	....	....	......	
		F.....	8 20 *ca.*	......	....	....	......	
25	....	P?....	18 10 35	......	....	....	......	
		L.....	18 26 ..	22	....	....	......	
		L.....	18 36 ..	15	....	....	......	
		F.....	19 20 *ca.*	......	....	....	......	Heavy micros.

MARYLAND. *U. S. C. & G. S. Magnetic Observatory, Cheltenham.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 10	....	e_N.....	13 59 25	......	....	....	......	Beginning probably later than S.
		e_E.....	14 01 44	......	....	....	......	
		e_N.....	14 01 44	......	....	....	......	
		i_N.....	14 02 08	......	....	....	......	
		L_E....	14 05 15	......	....	....	......	
		L_N....	14 04 50	......	....	....	......	
		M_E....	14 05 45	10	110	....	......	
		M_N....	14 05 18	10	....	100	......	
		C_E....	14 07 ..	......	....	....	......	
		C_N....	14 11 ..	9	....	....	......	
		F_E....	14 12 ..	......	....	....	......	
		F_N....	14 25 ..	......	....	....	......	
12	....	e_E.....	7 50 3[illegible]	......	....	....	......	No distinct phases.
		e_N.....	7 50 03	......	....	....	......	
		e_E.....	7 51 31	......	....	....	......	
		M_E....	7 52 39	......	20	....	......	
		M_N....	7 52 33	......	....	35	......	
		C_N....	7 56 ..	......	....	....	......	
		F_E....	7 59 ..	......	....	....	......	
		F_N....	8 02 ..	......	....	....	......	

MISSOURI. *St. Louis University, St. Louis.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 10	....	L_N....	13 39 ..	......	....	....	......	
		L_N....	13 44 45	......	....	....	......	
		L_N....	13 46 ..	......	....	....	......	Merges into next disturbance.
10	....	eP_N...	13 56 30?	......	....	....	2,100	
		S_N....	13 58 00	......	....	....	......	
		L_N....	13 58 48	......	....	....	......	
		F.....	14 56 ..	......	....	....	......	
12	....	eP_E...	7 46 ..	......	....	....	2,100	
		S.....	7 47 18	......	....	....	......	
		L.....	7 48 24	......	....	....	......	
		M.....	7 49 54	......	....	....	......	
		F.....	8 13 ..	......	....	....	......	

NEW YORK. *Cornell University, Ithaca.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km.*
Apr. 1	....	S?.....	5 08 ..	5	....	....	....
		eL....	5 19 ..	24	....	....	....
		F.....	5 46 ..	......	....	....	....
10	....	e......	13 53 38	5	....	....	....
		eL....	13 59 25	11	....	....	....
		F.....	14 52 ..	......	....	....	....
12	....	e......	7 46 10	5	....	....	....
		e......	7 49 00	4	....	....	....
		L.....	7 49 44	12	....	....	....
		F.....	8 11 ..	......	....	....	....

NEW YORK. *Fordham University, New York.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km.*
Apr. 10	....	iS.....	14 02 02	......	....	....	......
		L.....	14 04 44	......	....	....	......

VERMONT. *U. S. Weather Bureau, Northfield.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km.*
Apr. 10	....	e......	13 59 ..	......	....	....	......
		L.....	14 01 ..	......	....	....	......
		F.....	14 40 ..	......	....	....	......
12	....	e......	7 48 35	......	....	....	......
		F.....	8 05 ..	......	....	....	......

CANADA. *Dominion Observatory, Ottawa.*

1921.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Apr. 1	....	i_{NV}....	4 29 27	......	....	....	......	
		e?.....	4 45 38	......	....	....	......	
		eL_E...	5 01 30	......	....	....	......	
		L_E....	5 10 ..	45	....	....	......	
		L_N....	5 12 ..	38	....	....	......	
		L_E....	5 18 ..	22	....	....	......	
		L_N....	5 21 ..	24	....	....	......	
		L.....	5 28 ..	17	....	....	......	
		F.....	6 20 ..	......	....	....	......	
1	....	e......	12 57 ..	......	....	....	......	
		eL....	13 01 ..	......	....	....	......	
		L.....	13 05 30	17	....	....	......	
		F.....	13 15 ..	......	....	....	......	
2	....	e?.....	10 05 13	......	....	....	......	
		eL_E...	10 25 ..	38	....	....	......	
		L_E....	10 36 ..	26	....	....	......	
		L_{EV}...	10 46 ..	20	....	....	......	
		L_E....	10 51 ..	......	....	....	......	
		F.....	11 *ca.*	......	....	....	......	
5	....	e?.....	0 37 30	......	....	....	......	May not be seismic; no vertical component.
		F.....	0 45 ..	irreg.	....	....	......	
10	....	O.....	13 40 05	......	....	....	4,100	
		P.....	13 47 30	......	....	....	......	Good record on all three components.
		S.....	13 53 23	......	....	....	......	
		eL....	13 57 54	......	....	....	......	
		L.....	14 03 ..	8	....	....	......	
		L.....	14 19 ..	7	....	....	......	
		F.....	15 00 *ca.*	......	....	....	......	
10	....	e......	23 34 to					
			23 40 ..	......	....	....	......	Very slight indication of a record.
12	....	$iP?_{VE}$.	7 48 30	......	....	....	......	
		e......	7 49 to					
		L.....	7 56 ..	8	....	....	......	
		F.....	8 10 ..	......	....	....	......	
20	....	e_E.....	18 52 30	......	....	....	......	NS interfered with by micros; traces only on vertical.
		eL....	19 01 to	18 to				
			19 10 ..	16	....	....	......	
		F.....	19 11 ..	......	....	....	......	
22	....	eL....	7 25 48	......	....	....	......	
		L_E....	7 35 ..	18	....	....	......	Traces only on vertical.
		L_E....	7 40 ..	16	....	....	......	
		L_E....	7 52 ...	16	....	....	......	
		L_E....	8 03 ..	15	....	....	......	
		L_E....	8 10 ..	......	....	....	......	
		F.....	8 15 ..	......	....	....	......	
25	....	eL_E...	18 30 30	26	....	....	......	Long period sinusoidal L waves; considerably stronger on EW than on NS.
		L_E....	18 35 ..	23	....	....	......	
		L_E....	18 41 ..	18	....	....	......	
		L_E....	18 49 ..	16	....	....	......	
		F.....	19 10 ..	......	....	....	......	
27	....	e_N.....	21 47 to					
			21 51 ..	......	....	....	......	May not be seismic; on NS only; irregular.

TABLE 2.—*Instrumental seismological reports, April, 1921*—Con .

CANADA. *Dominion Meteorological Service, Toronto.*

1921.			H. m. s.	Sec.	μ	μ	Km.
Apr. 1		e	5 08 12				
		e	5 16 24				
		L	5 19 30				
		eL	5 23 36				
		eL	5 30 30				
		eL	5 35 24				
		M	5 33 21		*500		
		F	6 19 30				
1		e	12 53 12				
		e	13 01 00				
		L	13 03 06				
		eL	13 07 30				
		M	13 10 42		*400		
		eL	13 27 36				
		M2	13 30 18		*300		
		F	13 46 12				
2		e	10 24 24				
		iL	10 39 06				
		M	10 48 12		*200		
		eL	10 51 00				
		F	11 17 06				
3		eL	3 02 48				
		M	3 03 48		*200		
		F	3 17 42				
10		e	13 56 12				
		iL	13 59 54				
		M	14 00 36		*2,800		
		F	14 28 48				
12		iL	7 48 36				
		M	7 49 00		*300		
		iL	7 51 18				
		F	8 18 36				
20		L	19 00 42				
		eL	19 04 00				
		M	19 06 00		*300		
		F	19 25 06				
22		eL	7 25 54				
		M	7 27 42		*300		
		eL	7 33 30				
		L	•7 39 12				
		F	8 18 48				
25		L	18 33 35				
		eL	18 36 18				
		M	18 37 48		*600		
		F	19 16 06				

CANADA. *Dominion Meteorological Service, Victoria.*

1921.			H. m. s.	Sec.	μ	μ	Km.	
Apr. 1		S?	4 50 08					
		L	4 59 59					
		M	5 12 16		*500			
		F	6 15 13					
1		L	12 23 54					
		M	12 46 02		*1,200			
		F	13 20 57					
2		L	10 18 00					
		M	10 36 12		*200			
		F	11 05 53					
3		P	?4 40 53				950	May be off Queen Charlotte Island.
		iL	4 42 22					
		M	4 43 21		*400			
		F	4 52 51					
10		P	13 43 08					Felt on North end Queen Charlotte Id.
		M	13 46 34		*4,500			
		F	14 14 07					
			VERTICAL.					
		P	13 44 00					
		M	13 45 30		14			
		F	14 00 00					
12		P	7 32 15					Also near Q. C. I.
		M	7 33 43		*1,000			
		F	7 42 05					
20		L	19 19 15					
		M	19 22 12		*200			
		F	19 29 05					
22		L	7 06 55					
		M	7 10 22		*400			
		F	7 31 01					
25		L	18 08 54					
		M	18 16 27		*500			
		F	18 27 16					

* Trace amplitude.

No earthquakes were recorded during April, 1921, at the following stations:

CANAL ZONE. *Panama Canal*, Balboa Heights.

Reports for April, 1921, have not been received from the following stations:

ALABAMA. *Spring Hill College*, Mobile.
ALASKA. *U. S. C. & G. S. Magnetic Observatory*, Sitka.
ARIZONA. *U. S. C. & G. S. Magnetic Observatory*, Tucson.
DISTRICT OF COLUMBIA. *Georgetown University*, Washington.
MASSACHUSETTS. *Harvard University*, Cambridge.
NEW YORK. *Canisius College*, Buffalo.
PORTO RICO. *U. S. C. & G. S. Magnetic Observatory*, Vieques.

TABLE 3.—*Late reports (instrumental).*

DISTRICT OF COLUMBIA. *Georgetown University, Washington.*

1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 3		e_E	9 01 44					Heavy micros.
		e_N	9 01 33					
6		eP_E	7 31 24					Do.
		eS_E	7 36 46					
		eS_N	7 36 36					
		eL_E	7 41 48	16				
		eL_N	7 41 48	11				
		M_E	7 44 25	11	*2,100			
		M_N	7 44 12	9		*2,070		
		F	8 35 ..					
12		S_E?	10 42 24					S_E, S_N, indicated may be eL. Heavy micros.
		S_N?	10 42 24					
		eL_E?	10 46 18	25				
		L	10 48 08	27				
		F	11 03 ..					
21		e_N	4 14 14					EW does not show.
		eL_N?	4 19 24	9				
		F	4 40 ..					
24		L_E	10 26 15 to 10 40	18				NS does not show.
24		P_E	14 53 49					
		P_N	14 53 50					
		S_E	15 03 42					
		S_N?	15 03 42					
		eL_E	15 17 24	11				
		L_E	15 20 11	14				
		L_N	15 22 27	20				
		F	16 10 ..					
25		e_E	0 48 40					
		e_N	0 48 40					
		eL_E	0 50 24	13				
		eL_N	0 50 24	11				
		F	1 15 ..					
25		e_E	22 20 40					Heavy micros; NS does not show.
		L_E	22 33 44	11				
		F	?					
28		iP_E	7 55 10					
		iP_N	7 55 10					
		i_E	7 56 ..					
		i_N	7 56 ..					
		iS_E	8 00 56					
		iS_N	8 00 55					
		M_E1	8 02 15	6	*9,800			
		M_N1	8 00 54	11		*4,700		
		M_E2	8 03 05	6	*9,700			
		M_N2	8 02 46	8		*3,200		
		M_E3	8 04 08	8	*9,100			
		M_N3	8 04 16	8		*4,000		
		M_E4	8 05 55	9	*7,400			
		F	9 15 ..					
30		eP_E	15 21 31					Heavy micros.
		eP_N	15 21 31					
		S_E?	15 25 09					
		S_N?	15 25 09					
		F	17 *ca.*					

* Trace amplitude.

TABLE 3.—*Late reports (instrumental)*—Continued.

HAWAII. *U. S. C. & G. S. Magnetic Observatory, Honolulu.*

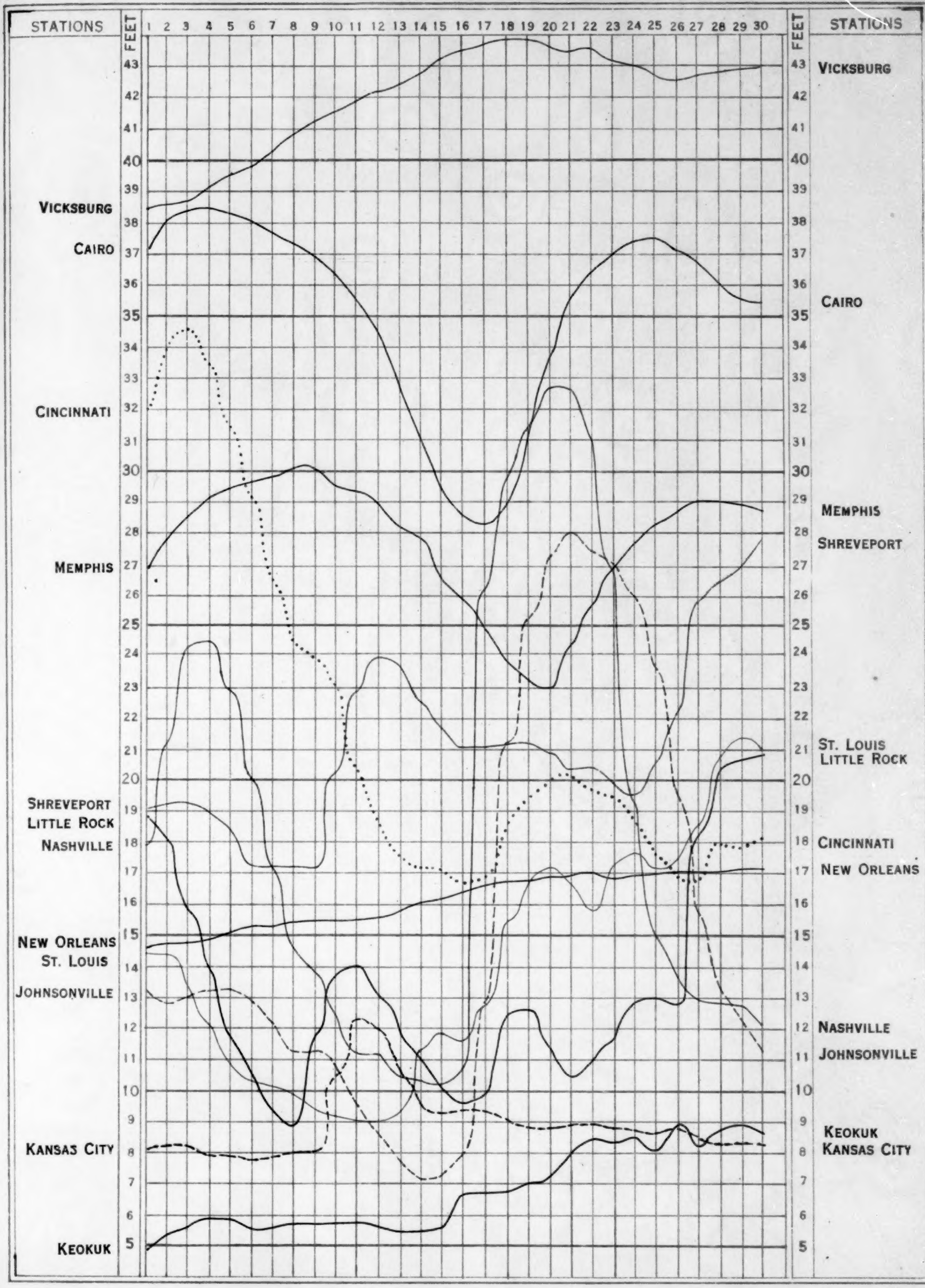
1921.			H. m. s.	Sec.	μ	μ	Km.	
Feb. 27	....	eP_E....	18 31 37	......	....	....	......	*These are the first records from the new Milne-Shaw seismograph installed during Feb. The damping factor is not fully determined, so the amplitude on the seismogram is given rather than the actual movement of the ground. Micros are continuously present with amplitudes ranging from 0.5 mm. to 2.0 mm. and predominant periods of about 4 sec. and 8 sec., the larger amplitudes usually coming with the longer period.*
		P_N....	18 31 31	......	....	....	......	
		eS_N....	18 37 25	......	....	....	......	
		i_E.....	18 37 57	15	....	....	......	
		i_N.....	18 37 56	13	....	....	......	
		L_E....	18 41 58	25	....	....	......	
		eL_N....	18 42 40	......	....	....	......	
		M_E....	18 42 10	14	*15,000	....	......	
		M_N....	18 47 13	18	....	*14,500	......	
		C_E....	19 10 ..	......	....	....	......	
		C_N....	19 23 ..	10	....	....	......	
		F_E....	20 14 ..	......	....	....	......	
		F_N....	20 08 ..	......	....	....	......	
Mar. 6	....	eL_E....	7 44 53	12	....	....	......	
		eL_N....	7 43 32	14	....	....	......	
		M_E....	7 48 50	8	*8,000	....	......	*Period of pendulum, 12 sec.; multiplication, 150. Sensitivity: N., 31.2 mm.; E., 25.8 mm.*
		M^N....	7 47 52	8	....	*7,500	......	
		C_E....	7 50 ..	7	....	....	......	
		C_N....	7 53 ..	7	....	....	......	
		F_E....	8 07 ..	......	....	....	......	
		F_N....	8 14 ..	......	....	....	......	
10	....	eL_E....	20 31 55	......	....	....	......	
		eL_N....	20 27 50	......	....	....	......	
		M_E....	20 34 00	......	*2,000	....	......	
		M_N....	20 33 40	......	....	*1,800	......	
		C.....	20 41 ..	......	....	....	......	
24	....	i_E.....	14 56 52	......	....	....	......	
		i_N.....	14 56 52	......	....	....	......	
		i_E.....	15 00 36	......	....	....	......	
		L_E....	15 03 00	26	....	....	......	
		L_N....	15 02 51	25	....	....	......	
		M_E....	15 06 37	19	*6,000	....	......	
		M_N....	15 06 28	19	....	*5,000	......	
		C_E....	15 08 ..	18	....	....	......	
		C_N....	15 10 ..	18	....	....	......	
		F_E....	15 13 ..	......	....	....	......	
		F_N....	15 20 ..	......	....	....	......	
28	....	iP_E....	8 00 21	4	....	....	......	
		P_N....	8 00 33	8	....	....	......	
		iS_E....	8 09 16	......	....	....	......	
		iS_N....	8 09 22	10	....	....	......	
		SR_N2.	8 17 11	......	....	....	......	
		L_E....	8 20 53	25	....	....	......	
		M_E....	8 21 17	22	*6,100	....	......	
		M_N....	8 09 38	......	....	*17,000	......	
		C_E....	8 28 ..	15	....	....	......	
		C_N....	8 27 ..	9	....	....	......	
		F_E....	8 38 ..	......	....	....	......	
		F_N....	8 51 ..	8	....	....	......	
29	....	S?....	22 27 12	......	....	....	......	
		eL_E....	22 35 47	......	....	....	......	
		L_N....	22 33 22	......	....	....	......	
		M.....	22 38 12	......	*2,000	*1,500	......	
		F.....	22 43 ..	......	....	....	......	
30	....	eP_E....	15 13 59	......	....	....	......	
		iS_E....	15 23 37	......	....	....	......	
		S_N....	15 24 19	......	....	....	......	
		eL_E....	15 37 56	......	....	....	......	
		M_E....	15 40 29	......	*1,700	....	......	
		F_E....	16 02 ..	......	....	....	......	
		F_N....	15 39 ..	......	....	....	......	

* Trace amplitude.

NEW YORK. *Cornell University, Ithaca.*

1921.			H. m. s.	Sec.	μ	μ	Km.
Mar. 6	....	e......	7 36 36	4	....	....	......
		eL....	7 41 30	14	....	....	......
		L.....	7 42 23	15	....	....	......
		F.....	8 17 ..	......	....	....	......
12	....	eS?....	10 38 30	4	....	....	......
		eL....	10 46 55	24	....	....	......
		F.....	11 07 ..	......	....	....	......
21	....	e......	4 14 07	4	....	....	......
		e......	4 20 07	7	....	....	......
		e......	4 24 12	5	....	....	......
		L.....	4 26 23	16	....	....	......
		F.....	4 40 ..	......	....	....	......
24	....	eL....	10 22 52	17	....	....	......
		F.....	10 54 ..	......	....	....	......
24	....	e_N....	14 53 24	4	....	....	......
		e_E....	15 03 02	5	....	....	......
		e......	15 11 36	21	....	....	......
		eL....	15 20 ..	22	....	....	......
		F.....	15 53 ..	......	....	....	......
25	....	e......	0 44 ..	3	....	....	......
		e......	0 47 ..	5	....	....	......
		eL....	0 48 48	3-12	....	....	......
		F.....	1 04 ..	......	....	....	......
28	....	P.....	7 55 27	4	....	....	......
		iS.....	8 00 35	11	....	....	......
		eL....	8 03 57	30	....	....	......
		F.....	9 22 ..	......	....	....	......
30	....	L.....	16 41 ..	24	....	....	......
		F.....	16 52 ..	......	....	....	......

Chart I. Hydrographs of Several Principal Rivers, April, 1921.



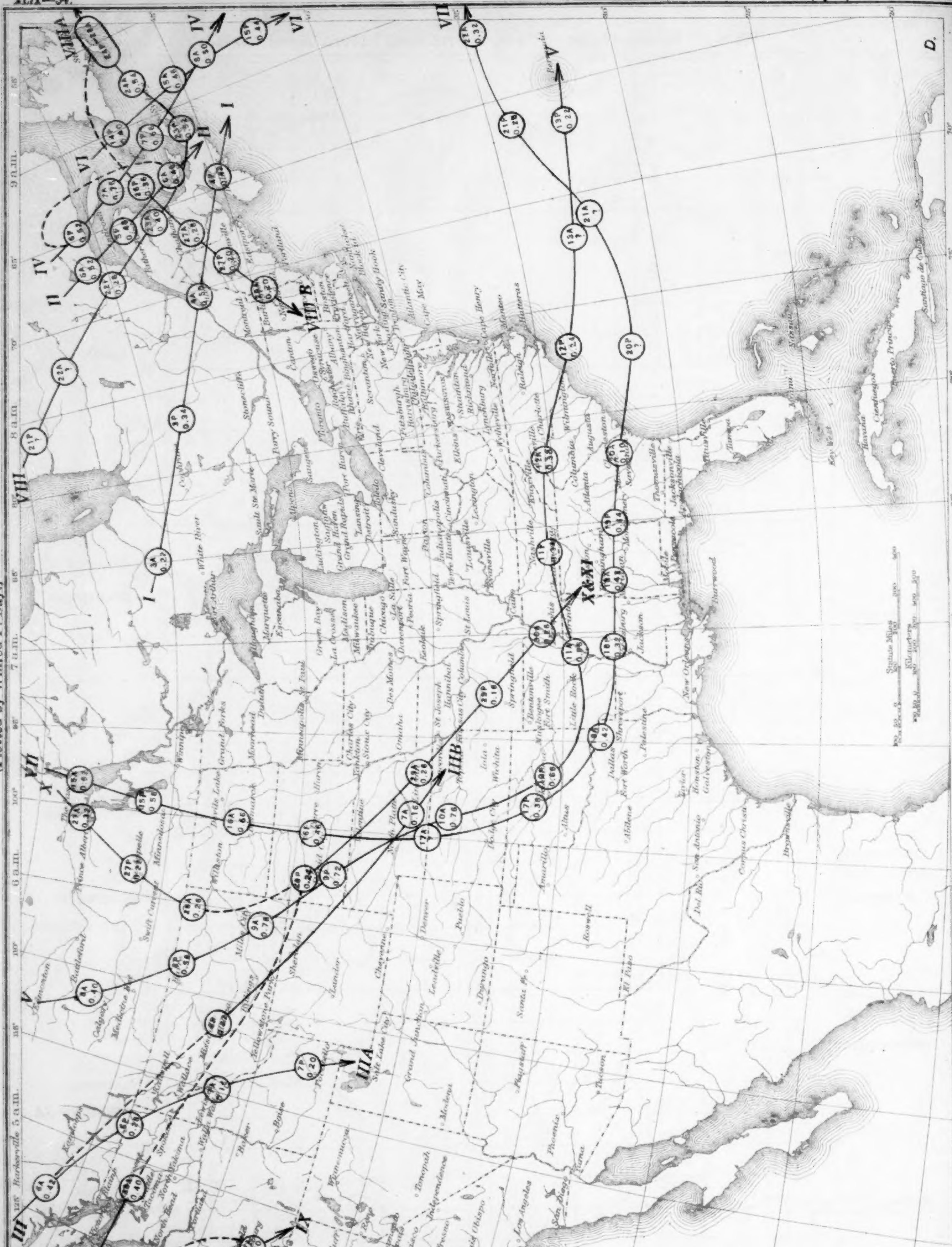


Chart II. Tracks of Centers of High Areas, April, 1921.
(Plotted by Wilfred P. Day.)

Chart III. Tracks of Centers of Low Areas, April, 1921.
(Plotted by Wilfred P. Day.)

Chart III. Tracks of Centers of Low Areas, April, 1921.
(Plotted by Wilfred P. Day.)

Chart IV. Departure (°F.) of the Mean Temperature from the Normal, April, 1921.

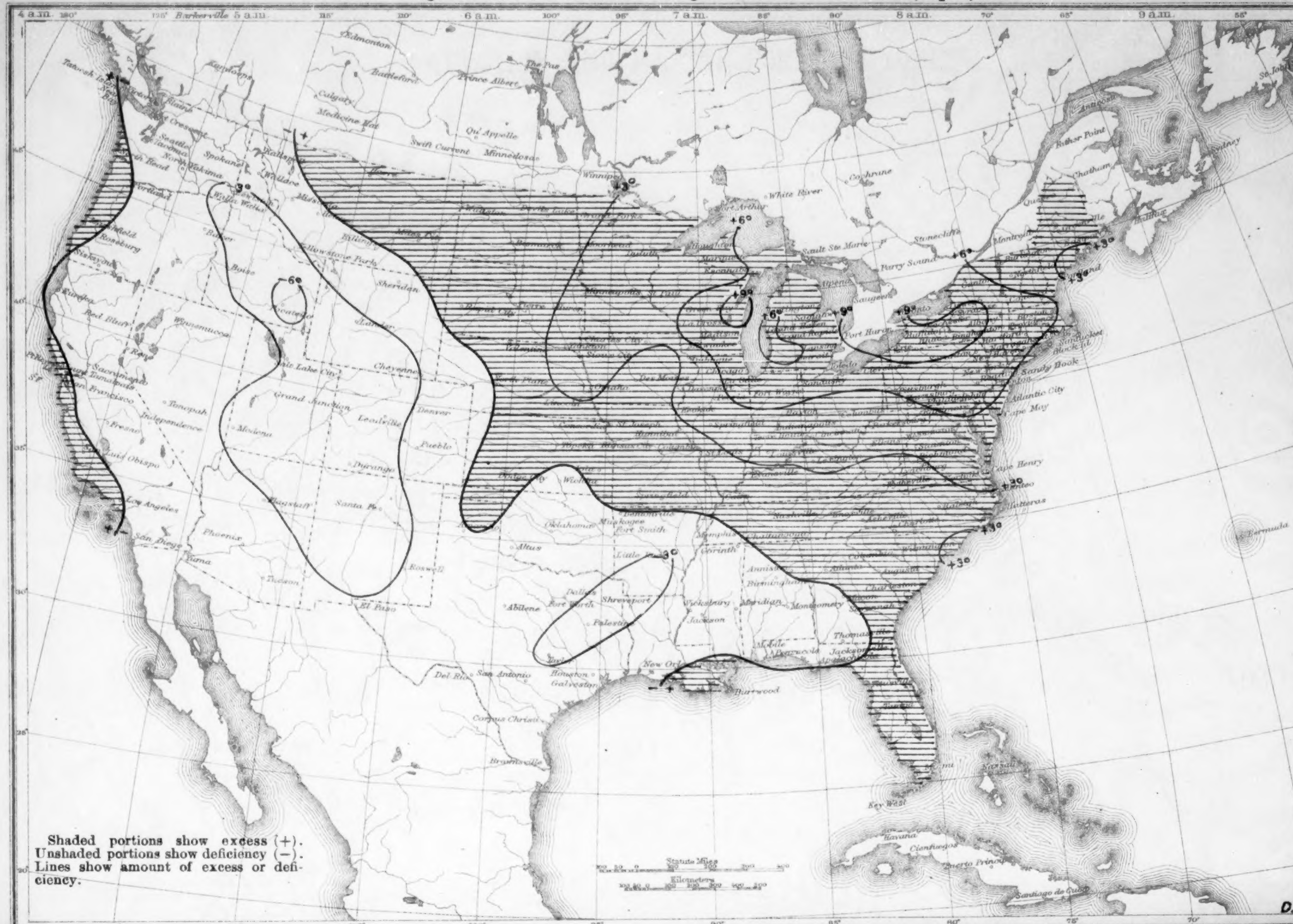


Chart V. Total Precipitation, Inches, April, 1921.

Chart V. Total Precipitation, Inches, April, 1921.

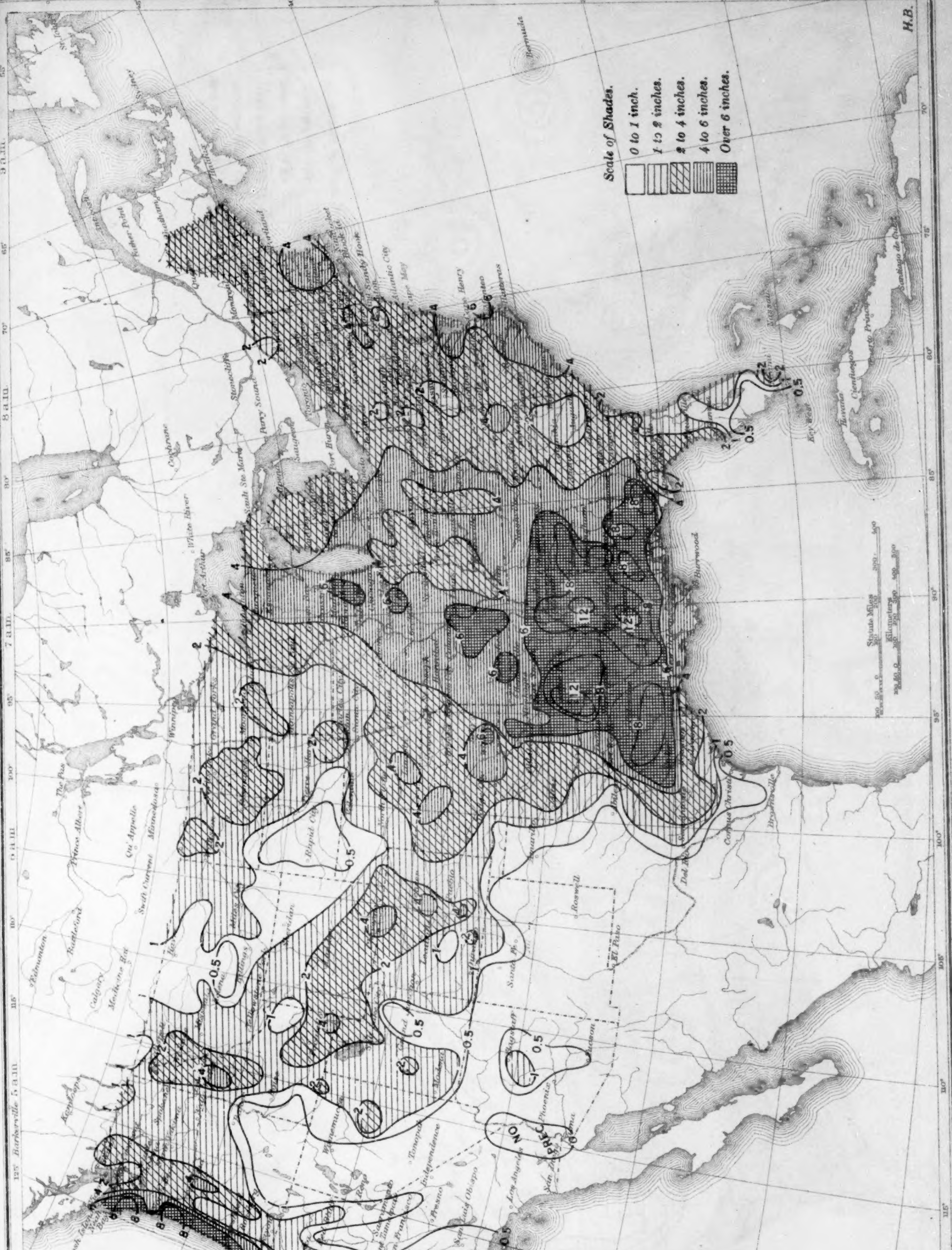


Chart VI. Percentage of Clear Sky between Sunrise and Sunset, April, 1921.

Chart VII. Isobars at Sea-level and Isotherms at Surface; Prevailing Winds, April, 1921.

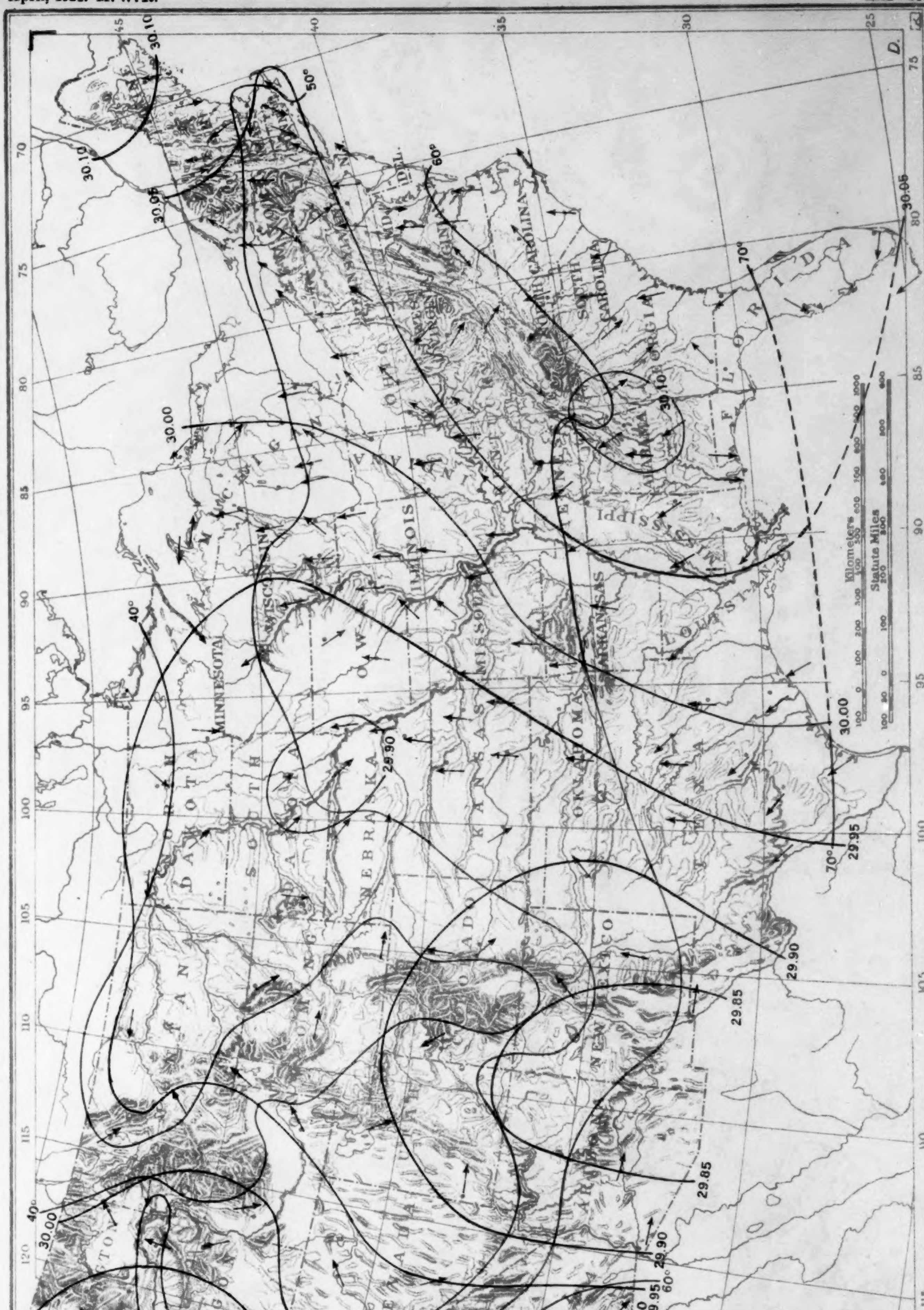


Chart VIII. Total Snowfall, Inches, April, 1921.

Chart IX. Weather Map of North Atlantic Ocean, April 8, 1921.
(Plotted by F. A. Young.)

Chart IX. Weather Map of North Atlantic Ocean, April 8, 1921.

(Plotted by F. A. Young.)

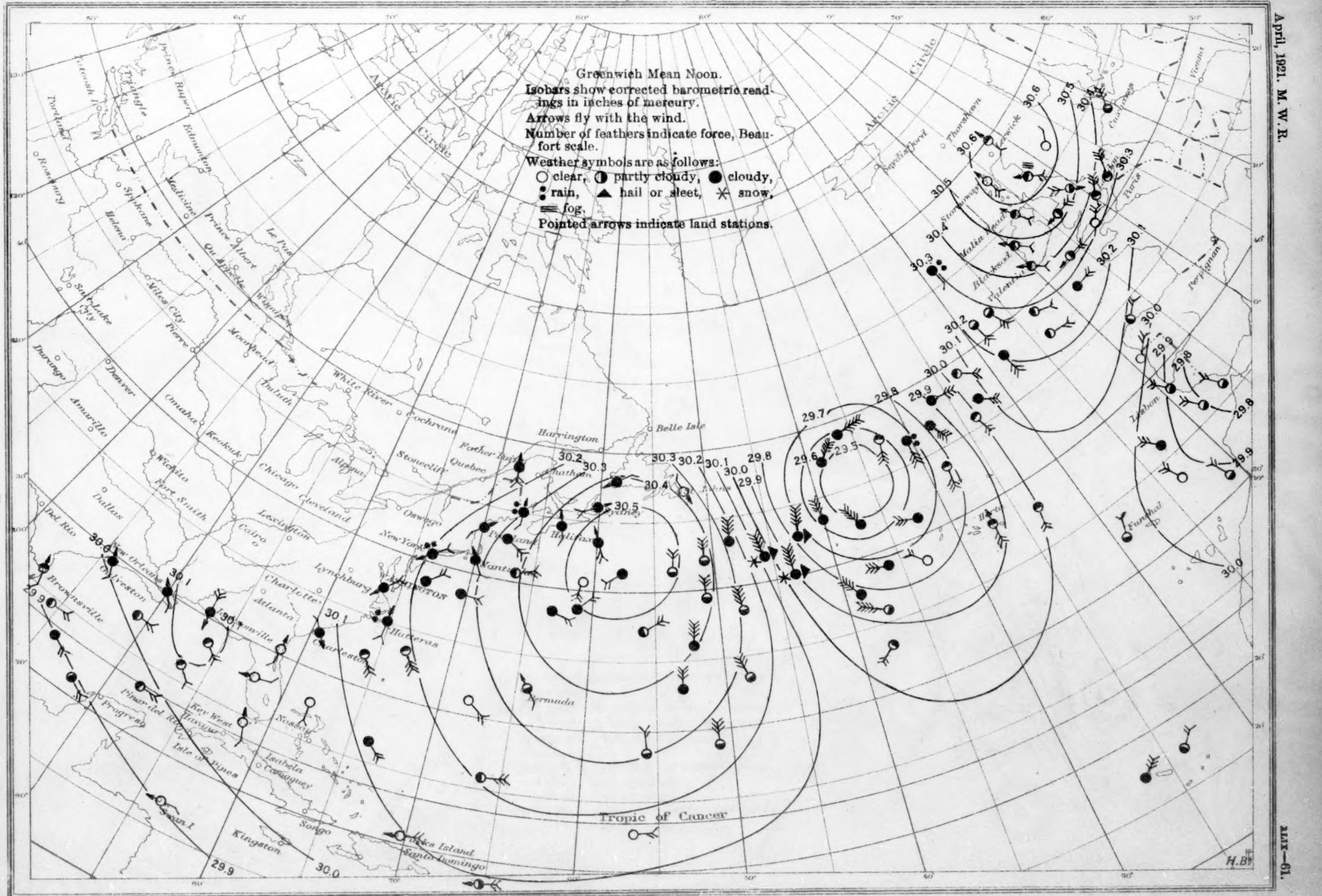


Chart X. Weather Map of North Atlantic Ocean, April 9, 1921.

(Plotted by F. A. Young.)

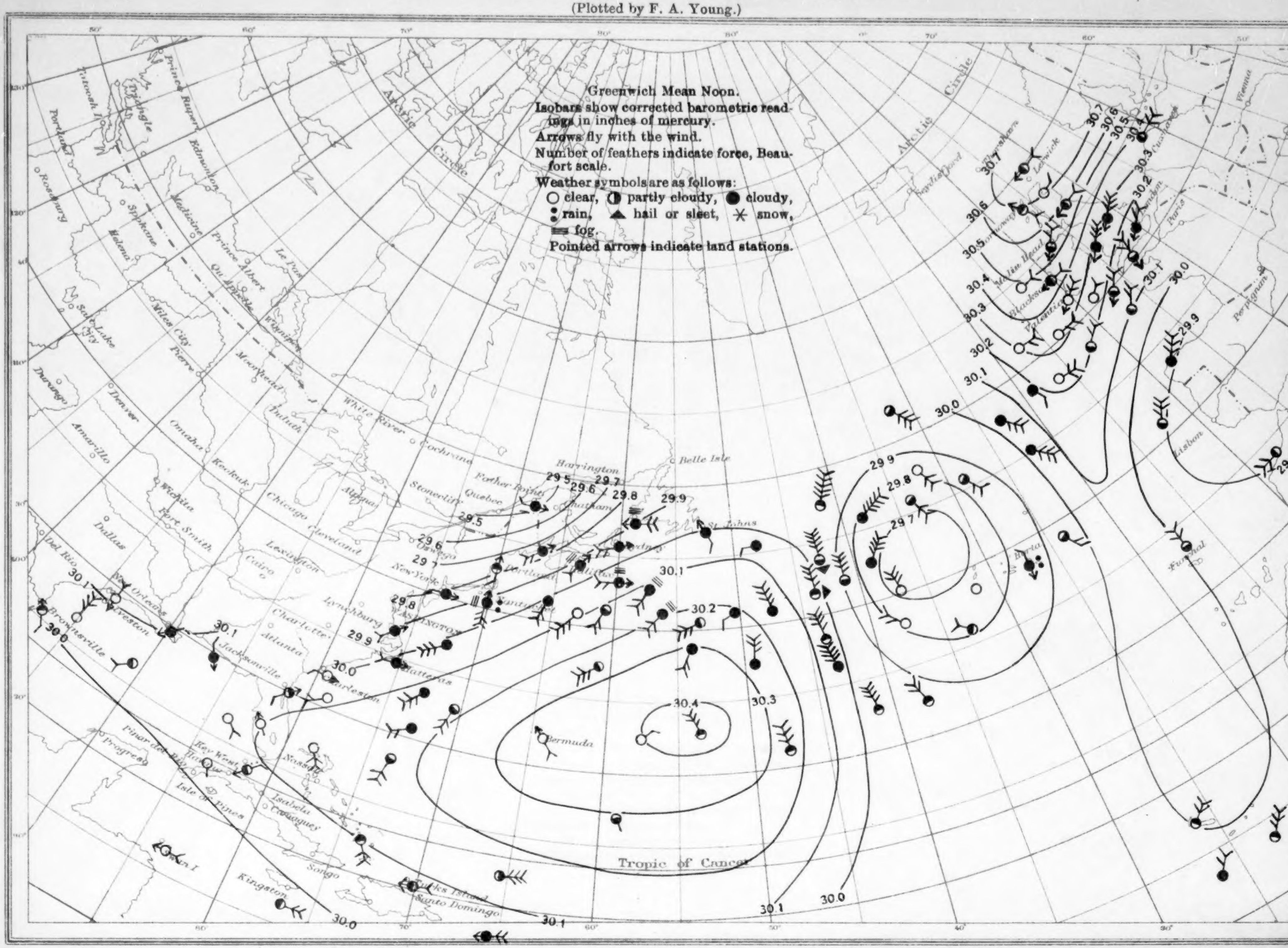


Chart XI. Weather Map of North Atlantic Ocean, April 11, 1921.

Chart XI. Weather Map of North Atlantic Ocean, April 11, 1921.
(Plotted by F. A. Young.)

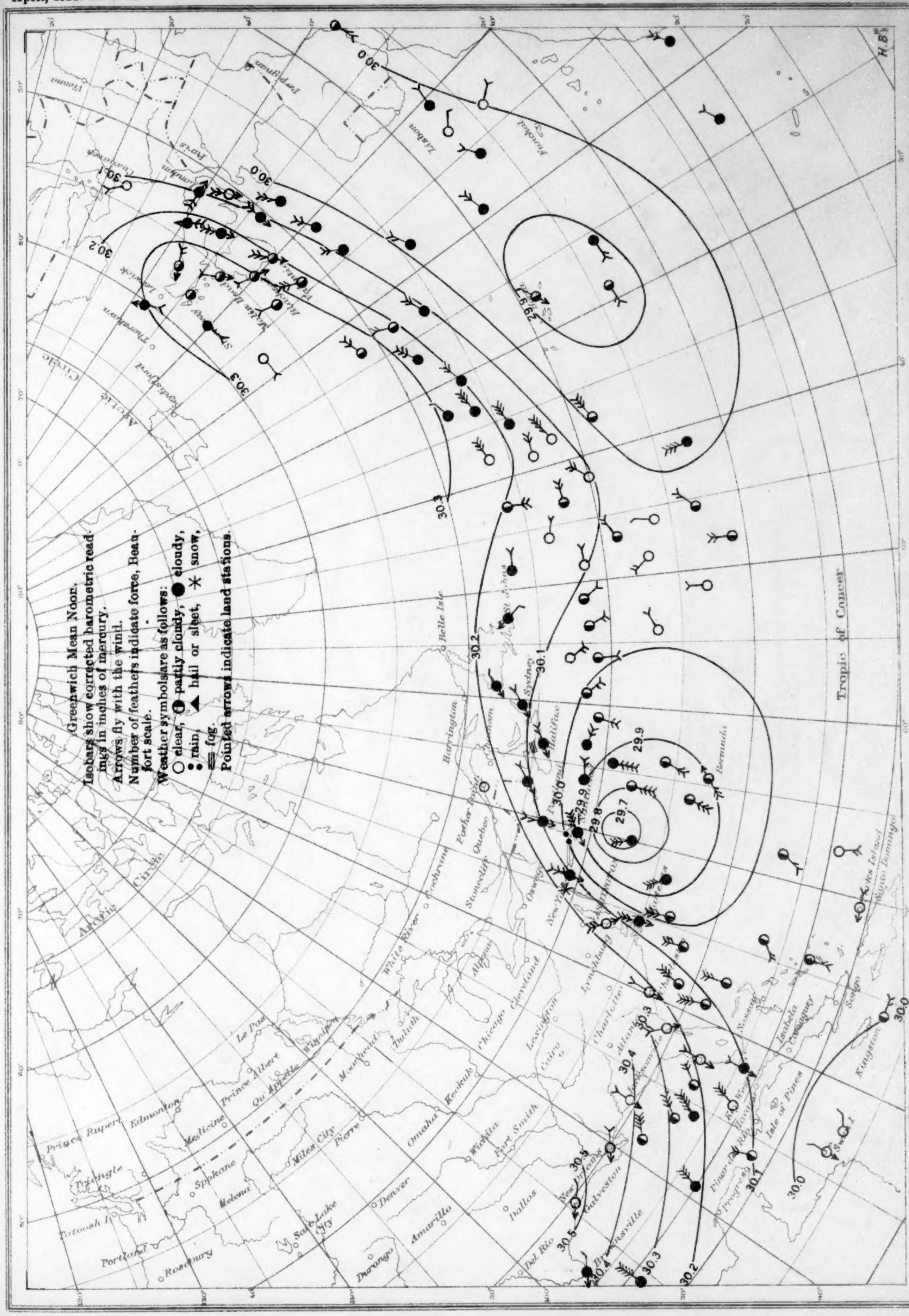


Chart XII. Weather Map of North Atlantic Ocean, April 28, 1921.

(Plotted by F. A. Young.)

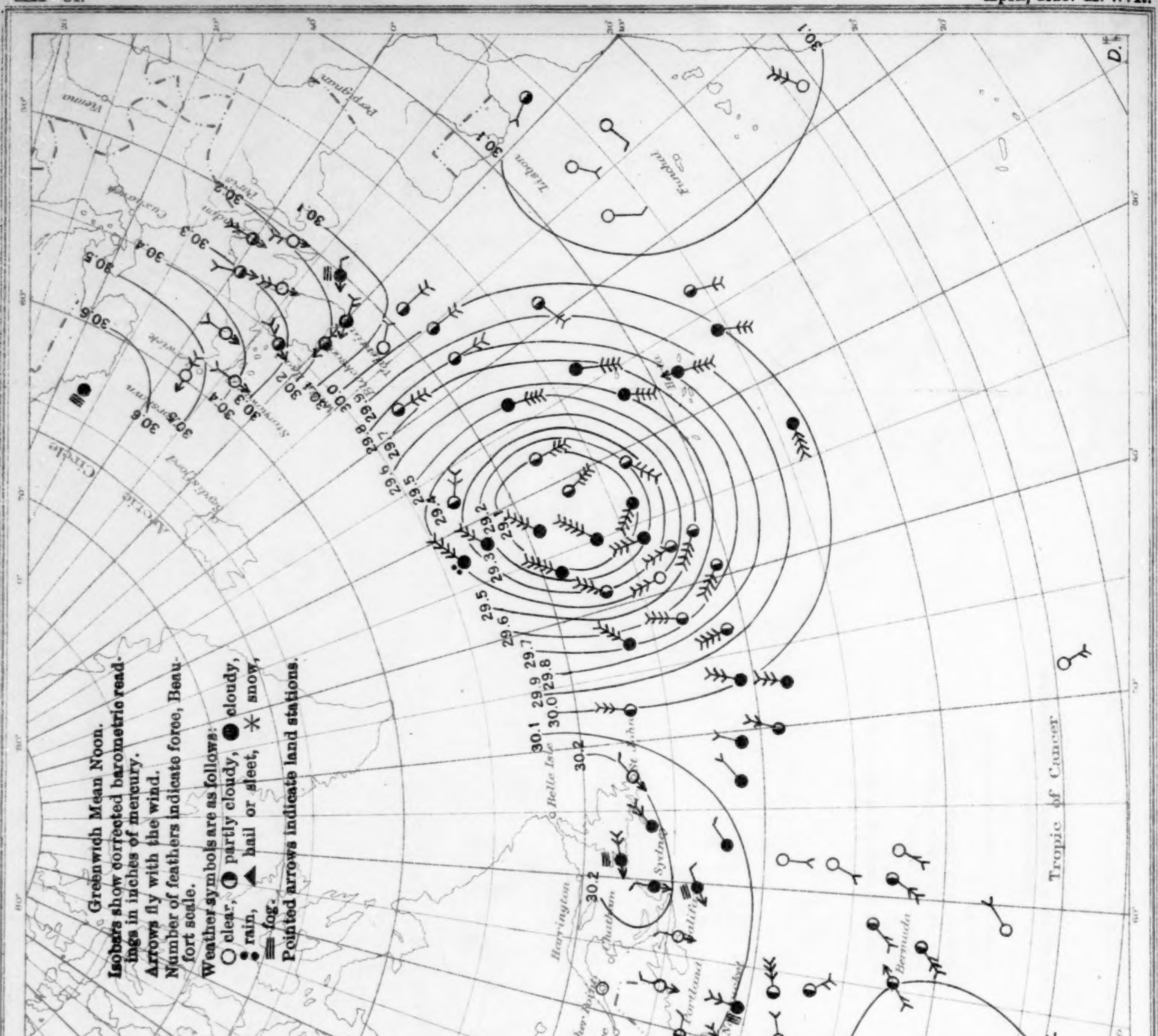
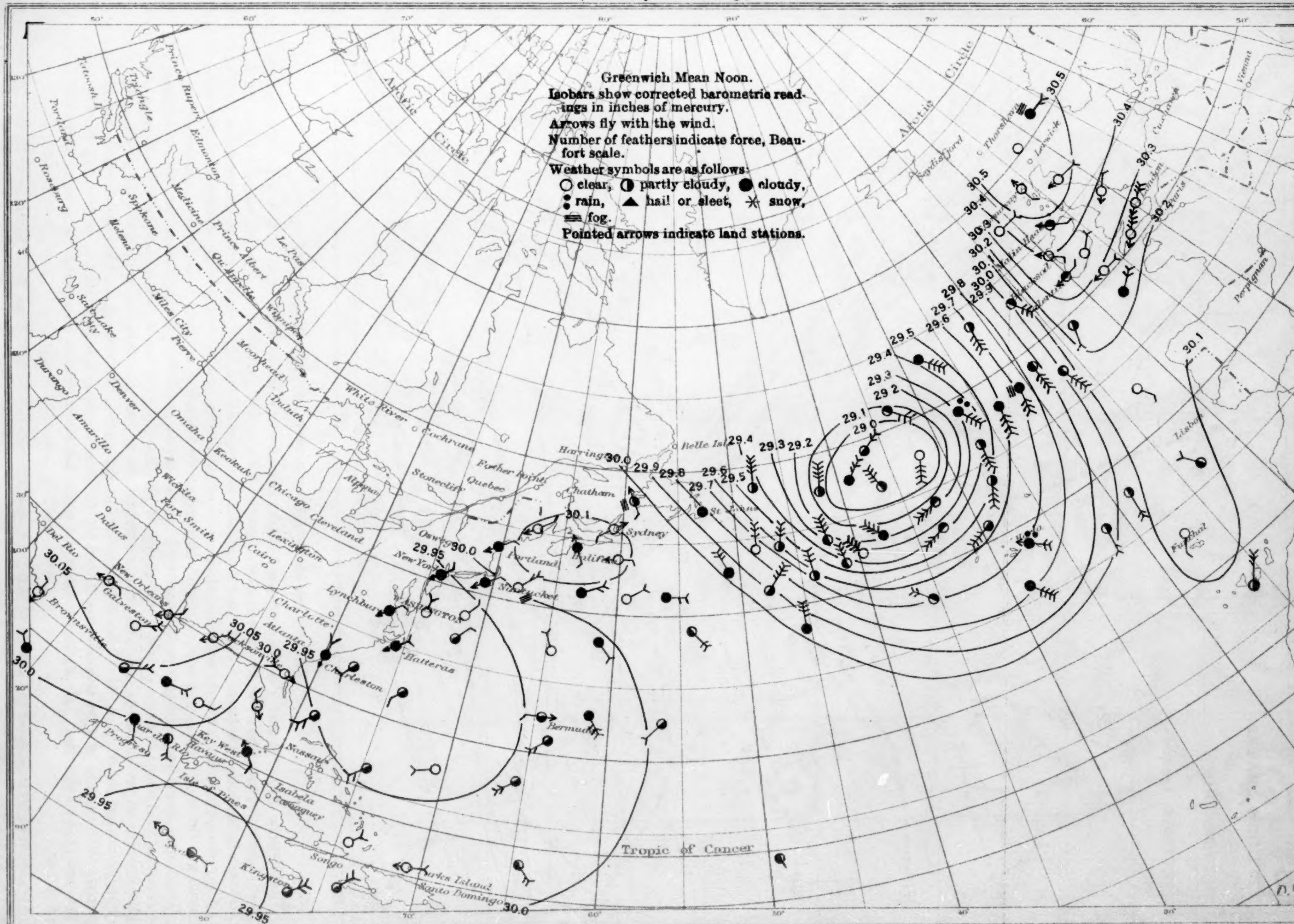
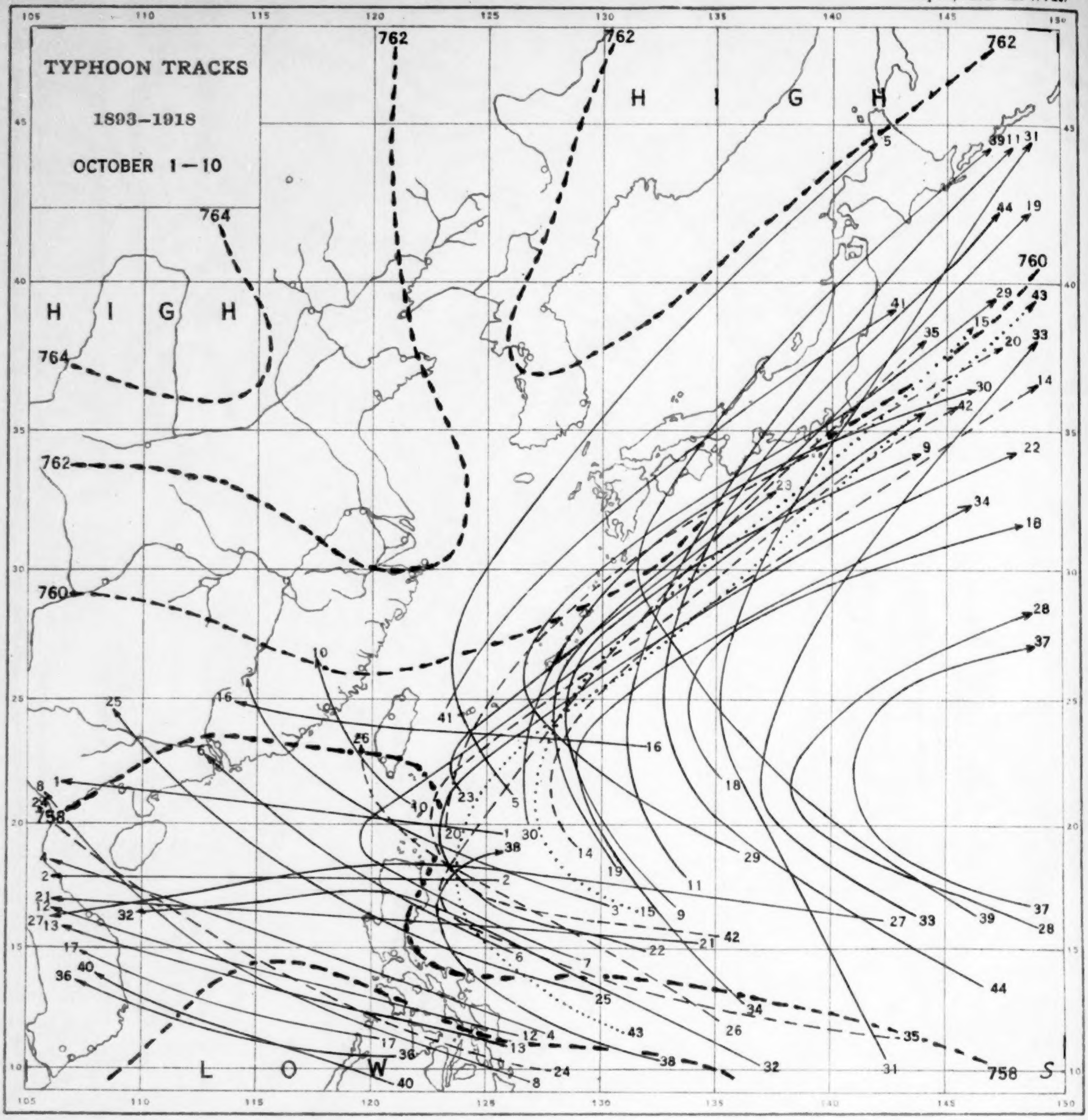


Chart XIII. Weather Map of North Atlantic Ocean, April 29, 1921.
(Plotted by F. A. Young.)



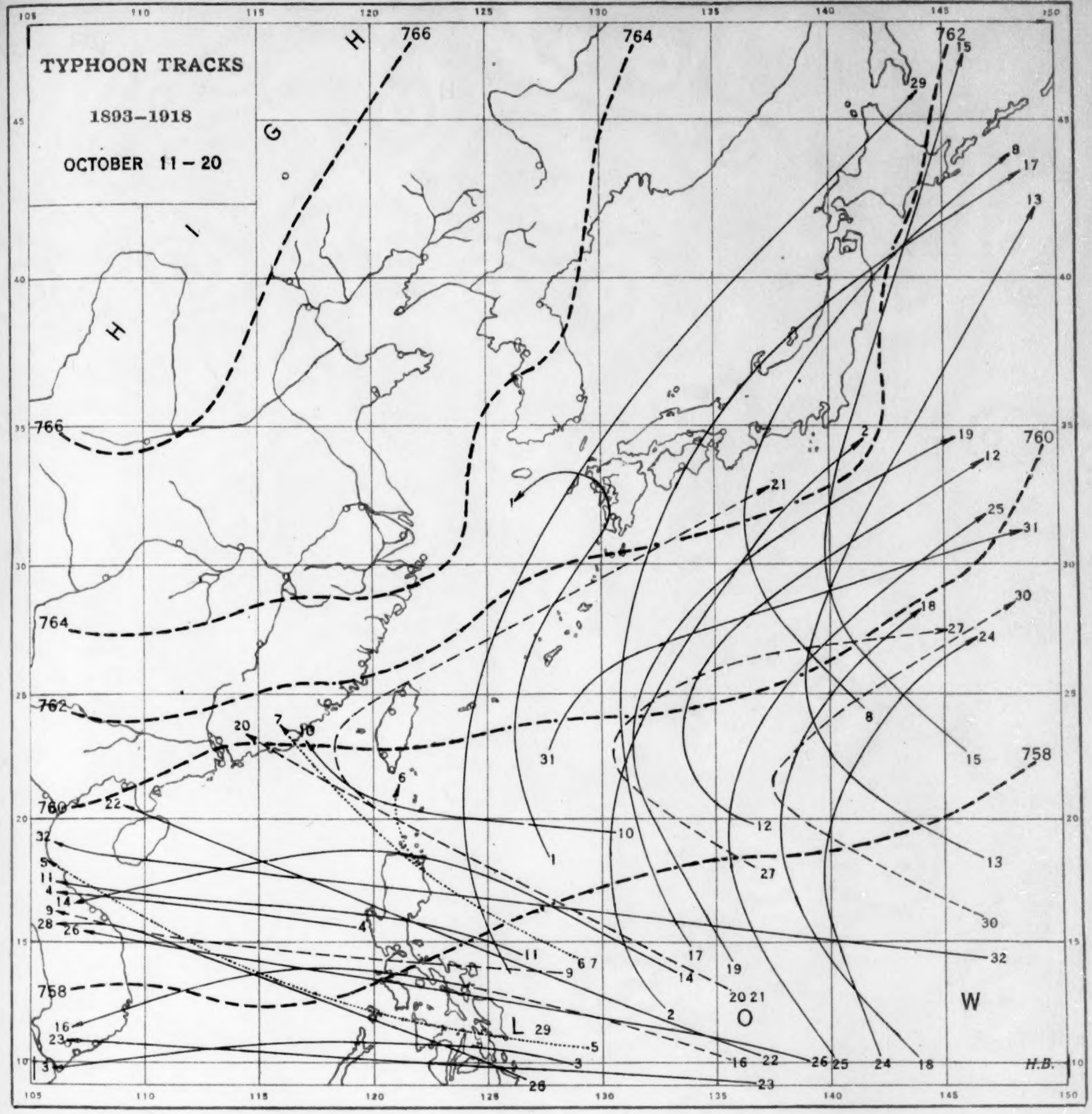


OCTOBER.—*Three charts: 95 tracks; three or four instances every year.*

First decade: 1-10.—44 tracks.—This first decade is the richest period of the whole year. The effect of the obstacle raised on the Continent against the incursions of the oceanic storms is such, that they are almost entirely expelled from land. Three centres only have ventured between Swatow and Amoy, and as soon as landed, they have been brought to a standstill and filled up. Only one typhoon has crossed the middle of the Eastern Sea, and a broken line joining Swatow to S. Formosa, then to Nagasaki and the E of Hokkaido, marks practically the western frontier that the enemy cannot cross any more.

The storms are numerous at this time, along the S coast of Japan, and it is remarkable how they follow the same SW-NE direction on a road about 300 miles broad that leads between Nippon and the Bonin to the open Pacific. There is also a thick bundle of tracks on the China Sea, where October is a bad month; no less than 16 typhoons are sweeping over the space between the Philippines and the coast of Indo-China, between the Gulf of Tongking and Padaran. The trajectories have a great tendency to recurve at two points, the one about long. 130° and lat. 25°, E of the Meiaco-Simas, and the other along the 123rd meridian, off the eastern coast of Luzon. The radient point of the tracks has still advanced southwards in latitude, far E of Mindanao, to the S of Yap.

[Reproduced from Atlas of the Tracks of 620 Typhoons, 1893–1918, by Louis Froc, S. J., Director, Zi-ka-wei Observatory, Zi-ka-wei–Chang-hai, 1920.]



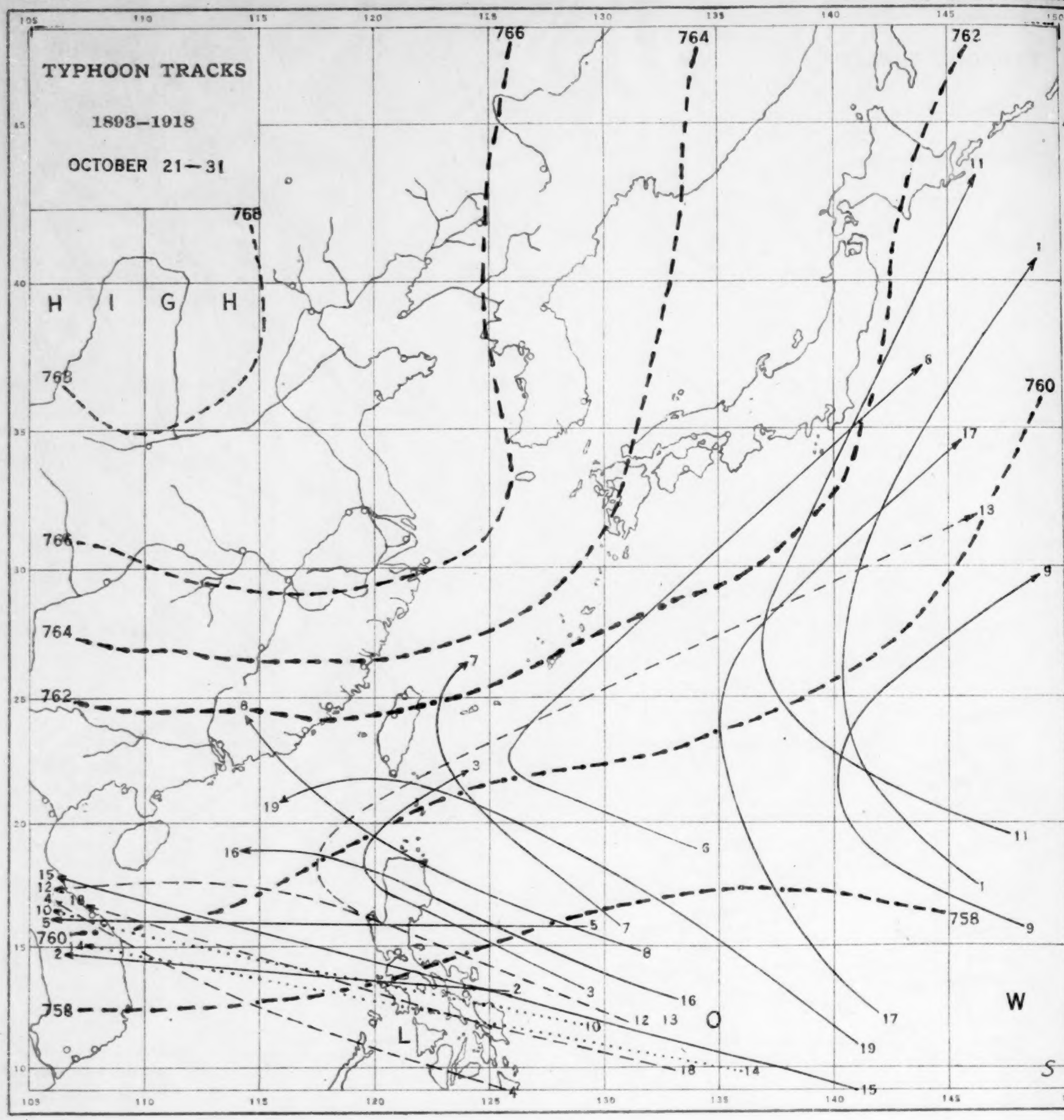
OCTOBER.—*Three charts: 95 tracks; three or four instances every year.*

Second decade: 11-20.—32 tracks.—The number of typhoons has decreased from 44 to 32 since the first decade, and we are going out of the typhoon season proper: the beginning of the month accounted for nearly the half of all the tracks of October. Now three centres only have ventured as far as the coast of Kwangtung; Formosa, the Eastern Sea and the Sea of Japan are practically a forbidden territory for the tropical storms. Some trajectories are scattered between the Bonin Group and the S. coast of Japan, where they do not form a dense bundle gathered close to a mean direction.

But at the same time an increasing activity is shown in the China Sea where the typhoons, keeping away from the Gulf of Tongking, come mostly to strike the coast between the extreme N. of Annam and lower Cochin-china with a great attraction towards the Paracels. Several centres have travelled straight from Palawan to Cochin-china: two more tracks are bent towards WSW.—The origin of the depressions is going down more and more to the S. of Yap.

Let us remark that, during this period, there is a broadening of the continental anticyclone; instead of the narrow spur projected previously towards the coast. Thus the isobar 764^{mm}, after running parallel to the Yangtze to reach the sea at Wenchow, bends there towards Korea to continue northwards to Wladivostok.

[Reproduced from Atlas of the Tracks of 620 Typhoons, 1893–1918, by Louis Froc, S. J., Director Zi-ka-wei Observatory. Zi-ka-wei–Chang-hai, 1920.]



OCTOBER.—*Three charts: 95 tracks; three or four instances every year.*

Third decade: 21-31.—19 tracks.—The number of typhoons is steadily decreasing: we do not find one typhoon every year during the last 10 days of the month; and we may say that their season is over, as far as the East of the 130th meridian is concerned. Only a few trajectories are seen between the Marianas and the Loochoos, and very few centres venture up to the Ballintang Channel, where they are soon repulsed or filled up. All the space to the NW of a line drawn up from the S end of Formosa to the SE corner of Japan is now perfectly free from their incursions.

But it must be remembered that the middle of the China Sea, along the 15th parallel, is still a dangerous region, and there remains a bundle of tracks, fairly dense, running from Palawan or the S. of Luzon towards the coast of Annam, in the neighborhood of Tourane. The Gulf of Tongking and Haïnan Island are practically free during this end of the month. The isobar 764mm that has gained ground, by some 4 degrees, towards the South and East, appears to be a kind of barrier impassable to the typhoons.

[Reproduced from Atlas of the Tracks of 620 Typhoons, 1893-1918, by Louis Froc, S. J., Director Zi-ka-wei Observatory, Zi-ka-wei–Chang-hai, 1920.]

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APRIL 1921.

CONTENTS.

CONTRIBUTIONS, ABSTRACTS, AND BIBLIOGRAPHY.

*Separates to be published.

WEATHER OF THE MONTH.

†In marine separate.